AIR POLLUTION IN DONORA, PA.

Epidemiology of the Unusual Smog Episode of October 1948

PRELIMINARY REPORT

PUBLIC HEALTH BULLETIN NO. 306

FEDERAL SECURITY AGENCY • Public Health Service

1949

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PRELIMINARY REPORT

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Public Health Service
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Washington, D. C.

1949

THE whole Nation was shocked when 20 persons died and several thousand more became ill during the smog that enveloped the town of Donora, Pa., during the last week of October 1948. To most of us this was a new and heretofore unsuspected source of danger. Although we have been concerned for many years with the general problem of pollution of the air in connection with smoke, we have regarded that as a nuisance and annoyance rather than a serious hazard to health.

Our scientists tell us that the Donora episode was a rare phenomenon. We hope and pray it will never recur. This study by the Public Health Service into the Donora episode, the most exhaustive ever made on a problem in air pollution, is a step toward positive assurance that such a thing will not happen again.

There is another way we may now use the knowledge we have gained at Donora. The episode has focussed our attention on the larger problem; that is, the almost completely unknown effects on health of many types of air pollution existing today. We must move to an attack on this new frontier of atmospheric pollution.

Oscar R. Ewing

Administrator

Foreword

THIS study is the opening move in what may develop into a major field of operation in improving the Nation's health. We have realized, during our growing impatience with the annoyance of smoke, that pollution from gases, fumes, and microscopic particles was also a factor to be reckoned with. But it was not until the tragic impact of Donora that the Nation as a whole became aware that there might be a serious danger to health from air contaminants.

Before the Donora episode there had been only one other similar incident in history. In 1930, in the Meuse Valley of Belgium, a period of intense fog in a heavy industrial area resulted in the death of 60 persons. Although several studies were made of those fatalities, the Donora study is the first thorough investigation into every facet of an air-pollution problem, including health effects as well as deaths.

The Donora report has completely confirmed two beliefs we held at the outset of the investigation. It has shown with great clarity how little fundamental knowledge exists regarding the possible effects of atmospheric pollution on health. Secondly, Donora has emphasized how long-range and complex is this job of overcoming the problem of air pollution—after we get the basic knowledge on its effects. This intensive piece of work by the Division of Industrial Hygiene of the Public Health Service will have its greatest value as the blueprint for our plan of proceeding to get that knowledge.

Our first step now, of course, is immediate basic research. We need to investigate for instance, what long-range effect continued low concentrations of polluted air has on the health of individuals—not only healthy individuals, but those with chronic diseases and the aged and children. We know nothing about the indirect effect of air pollution on persons with diseases other than those of the respiratory tract. We also need immediate research into another indisputable effect of air pollution; its ability to shut out some of the healthful rays of the sun.

When we find the answers to all of these unknowns, we can proceed to the problem of eliminating the causes. As a proof that air pollution is a health matter, as a model for future studies in air pollution, and as an important phase of our increasing efforts in the field of environmental health, this study will be invaluable.

Leonard A. Scheele

Surgeon General

Origin of Study

During the last week of October 1948 a heavy smog settled down over the area surrounding Donora, Pa. Weather men described it as a temperature inversion and anticyclonic conditions characterized by little or no air movement, prevailing over a wide area encompassing western Pennsylvania, eastern Ohio, and parts of Maryland and Virginia. This prolonged stable atmospheric condition was accompanied by fog and permitted the accumulation of atmospheric contaminants resulting in dense smog, particularly in highly industrialized areas. Smogs of short duration are not unusual and except for discomfort due to irritation and nuisance of the dirt and poor visibility, no unusual significance is attached to such occurrences.

This particular smog encompassed the Donora area on the morning of Wednesday, October 27. It was even then of sufficient density to evoke comments by the residents. It was reported that streamers of carbon appeared to hang motionless in the air and that visibility was so poor that even natives of the area became lost.

The smog continued through Thursday, but still no more attention was attracted than that of conversational comment.

On Friday, however, a marked increase in illness began to take place in the area. By Friday evening the physicians' telephone exchange was flooded with calls for medical aid, and the doctors were making calls unceasingly to care for their patients. Many persons were sent to nearby hospitals, and the Donora Fire Department, the local chapter of the American Red Cross, and other organizations were asked to help with the many ill persons.

There was, nevertheless, no general alarm about the smog's effects even then. On Friday evening the annual Donora Hallowe'en parade was well attended, and on Saturday afternoon a football game between Donora and Monongahela high schools was played on the gridiron of Donora High School before a large crowd.

The first death during the smog had already occurred, however, early Saturday morning—at 2 a. m., to be precise. More followed in quick succession during the day and by nightfall word of these deaths was racing through the town. By 11:30 that night 17 persons were dead. Two more were to follow on Sunday, and still another who fell ill during the smog was to die a week later on November 8.

On Sunday afternoon rain came to clear away the smog. But hundreds were still ill, and the rest of the residents were still stunned by the number of deaths that had taken place during the preceding 36 hours. That night the town council held a meeting to consider action, and followed with another on Monday night. By this time emergency aid was on its way to do whatever possible for the stricken town.

On Tuesday morning a telephone call came to the Division of Industrial Hygiene, of the Public Health Service in Washington. It requested that the Division take steps immediately to bring to bear on the Donora crisis its experience in combatting industrial health hazards. The following day a staff member of the Division arrived in Donora to make a preliminary survey of what could be done.

This telephoned request to the Division of Industrial Hygiene was later formally repeated on behalf of the Borough Council of Donora, the Department of Health of the State of Pennsylvania, and the United Steelworkers of America, CIO.

The Division of Industrial Hygiene threw every resource possible into an investigation of the Donora smog. Some 25 persons were assigned to the field team sent in to make an exhaustive study of what happened during the smog. Dr. Helmuth H. Schrenk was placed in general charge of the investigation, Dr. Harry Heimann was named to direct the medical aspects, and Mr. George D. Clayton was placed in charge of the field team in Donora. This report presents the results of 5 months' intensive field work by that team, and the additional personnel assigned by the United States Weather Bureau.

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J. J. Bloomfield, Assistant Chief,
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Appreciation is expressed to the people of the Donora area and to the officials of the Borough of Donora, especially, Burgess A. Z. Chambon, and the Donora Special Investigating Committee, composed of Chairman J. Duda, Jr., A. Takach, F. Urban, and Special Counsels J. Richardson and H. R. Stahlman. Mention is made, also, of the officials of the Donora and Webster schools, and the Donora Board of Health.

We wish, also, to thank Secretary of Health N. W. Vaux, Dr. J. Shilen, and G. E. Greenwood of the Pennsylvania Department of Health; United Steelworkers of America, CIO; American Steel & Wire Co.; local newspapers and radio station; Donora Medical Society; Donora dentists; local clergy; Charleroi-Monessen Hospital, Charleroi, Pa.; Memorial Hospital, Monongahela, Pa.; and the following industrial companies of the Donora area: Burrell Construction & Supply Co., Carnegie-Illinois Steel Corp., Combustion Engineering Co., Corning Glass Works, The France Slag Co., Liggett Spring & Axle Co., Page Steel & Wire Co., Pennsylvania Industrial Chemical Corp., Pennsylvania Railroad Co., Pittsburgh Steel Co., Standard Dry Wall Products, and West Penn Power Co.

Assistance was also obtained from the following industrial sick benefit organizations: Donora Zinc Works Mutual Benefit Society, Donora Wire Works Mutual Benefit Society, Donora Steel Welfare Club, and the Benefit Association of Railway Employees.

Able assistance was provided by the United States Coast Guard, United States Bureau of Mines, United States Bureau of the Census, and the Utah Department of Health. The National Office of Vital Statistics gave freely of its time and material.

Although many persons of the Division of Industrial Hygiene, Public Health Service, assisted in this investigation and in the preparation of the report, mention is made of the following: F. J. Acosta, Jr., R. E. Bales, C. C. Shinn, L. T. Fairhall, Betty M. Flick, E. P. Floyd, Elizabeth S. Frasier, J. W. Fridl, Margaret E. Hook, Frances Hyslop, D. M. Keagy, Irene M. Lima, V. B. Perone, D. E. Rushing, B. E. Saltzman, J. A. Sutton, N. A. Talvite, and C. D. Yaffe.

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I. Introduction

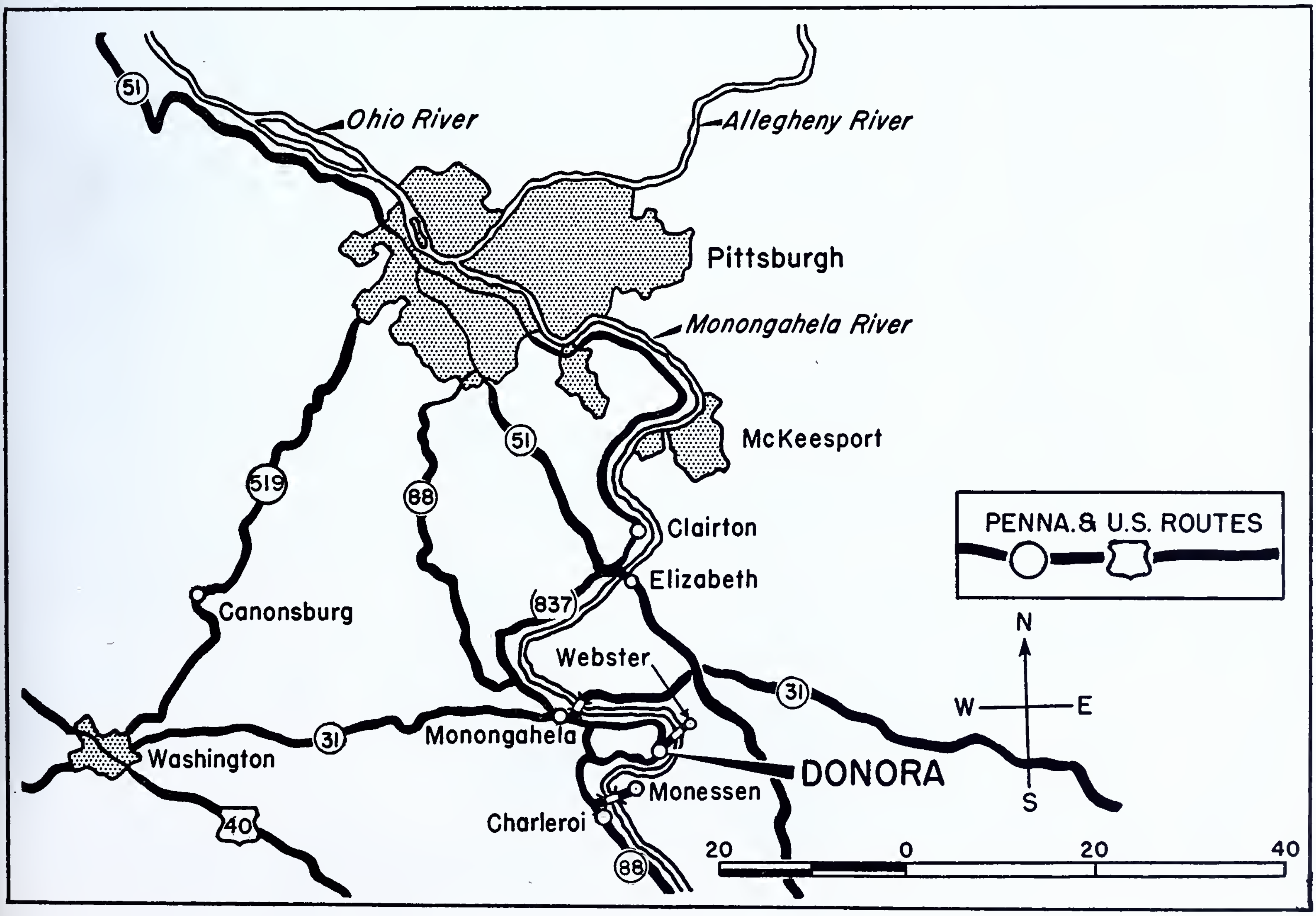
THE DONORA AREA

The Borough of Donora is located on the Monongahela River in Washington County, Pa., about 30 miles south of Pittsburgh. Other industrial towns in the nearby vicinity are Charleroi and Monessen upstream and Monongahela City a few miles downstream. Adjacent to Donora is Carroll Township, and the community of Webster is situated directly across the river from Donora, the latter two being connected by a bridge. Map 1 shows the southwestern portion of Pennsylvania which includes Donora and a number of nearby communities.

Donora is located on the inside of a sharp horseshoe bend in the Monongahela River, as shown in Map 2, which is a photographic reproduction of the United States Geological Survey map of the Brownsville quadrangle of Pennsylvania. The area along the river bank is occupied by a steel and wire plant, and by a zinc plant. The steel plant extends for about 2 miles south of the Donora-Webster bridge, and the zinc plant for about 1 mile north of the bridge along the river. The main business district lies adjacent to the plants and the residential area extends to the top of the hills.

At river-bank level the altitude above sea level is 760 feet. As indicated by the contour lines, hills on the east bank of the river rise abruptly to a height of about 1,100 feet. The hills on the Donora side of the river rise more gradually to a height of 1,150 feet.

The population of the Donora area is about 14,000, approximately 13,000 living in Donora and about 1,000 in Webster. The majority of the people are of Slavic descent



MAP No. 1.—*Road map showing Donora's geographical relationship to Pittsburgh.*

with small Spanish and Negro minorities present. Of the 5,000 people gainfully employed, about 3,000 work at the steel and zinc plants.

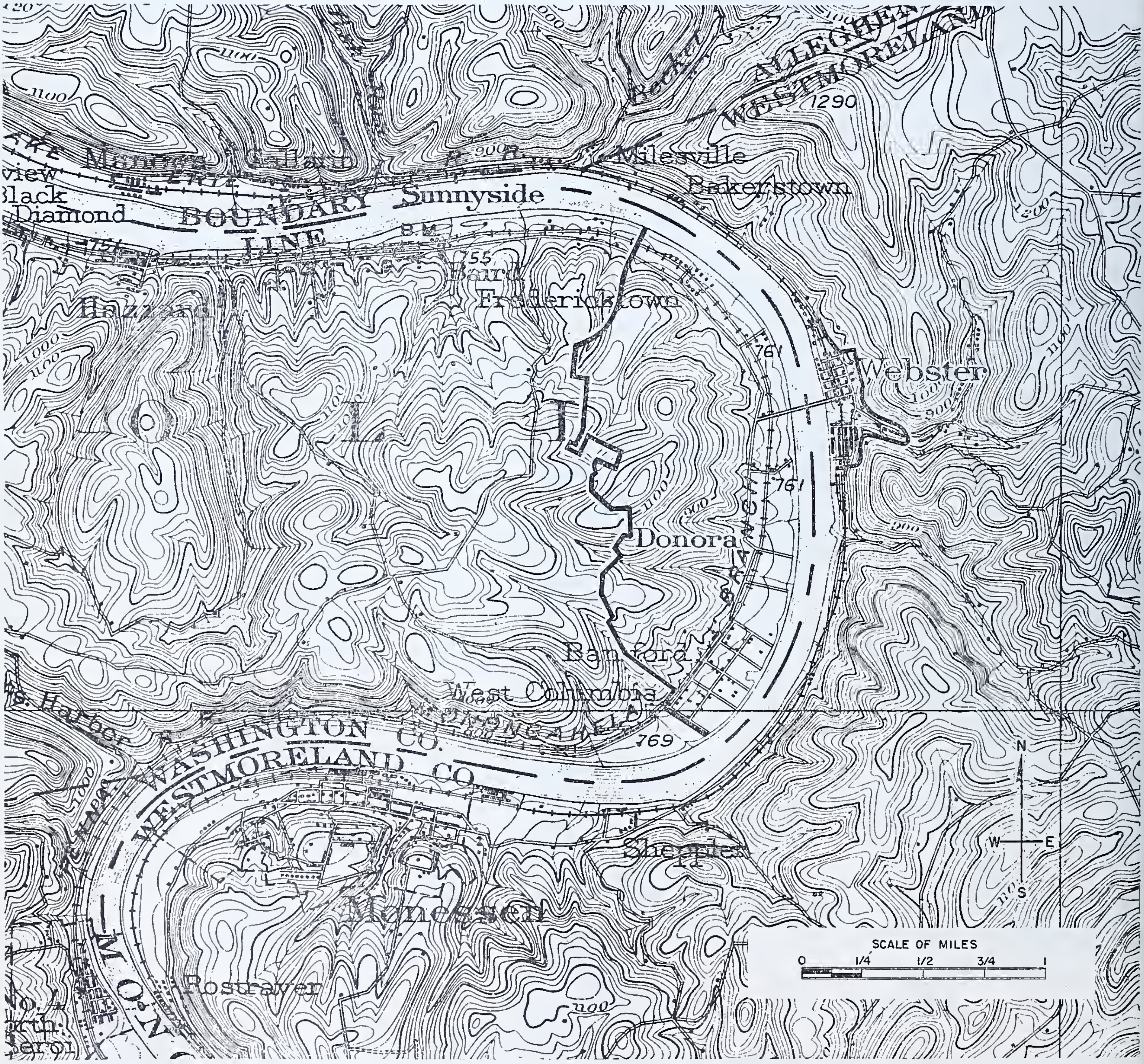
The homes in Donora are almost all of wood or brick construction. Very few of the estimated 2,300 houses are over two stories high.

A greater part of the land in the area back from the river is comprised of small farms. A number of coal mines are also located throughout the area.

Industries

Donora's industrial life is dominated by a steel and wire plant, and a zinc plant. The steel and wire plant had its beginning in 1900, when the construction was started of the blast furnaces, open-hearth department, and blooming mill. In 1901, two looping-rod mills, a wire-drawing department, and a wire-finishing department were constructed. The finished products of the plant include wire, nails, barbed wire, bale ties, welding rods, stranded cable, welded concrete reinforcing, and woven fence. The zinc plant was built in 1915, and is of the horizontal-retort type. The products of the plant include zinc, cadmium, unrefined lead, and sulfuric acid.

Other heavy industries in the nearby area include two steel companies and one byproduct coke plant in Monessen, a steel and byproduct coke plant in Clairton, a glass company



Map No. 2.—*Geological survey map of Donora and vicinity. (See also figure 67.)*

in Charleroi, a power company, and a railroad yard in Elrama.

Two railroads run through the Monongahela valley in this region, one on the Donora side of the river and the other on the opposite bank. The river traffic on this section of the river is relatively heavy.

PLAN OF INVESTIGATION

The plan of the investigation was based on two main objectives (1) to ascertain the cause of the Donora episode, and (2) to obtain information applicable to preventing future occurrences. At the same time consideration was given to obtaining additional information of a fundamental nature which would be applicable to the general problem of atmospheric pollution.

To accomplish these objectives, plans were made to investigate the three major factors: (1) effects on people and animals, (2) contaminants, and (3) meteorological conditions. This decision logically divided the investigation into three phases: (1) biological, (2) engineering, and (3) meteorological.

The fact that the investigation began some 2 months after the acute episode had subsided, decidedly influenced the plan of the investigation. It is, of course, apparent that since, in the main, the acute illness was of such a nature that recovery was rapid as soon as the smog was dissipated, it was not expected that residual disease would be found as an important factor. Further, the level of air contamination was markedly altered when the smog cleared. It, therefore, became necessary to try to reconstruct the picture from data collected after the occurrence of the episode.

Biological

It was the function of the biological studies to collect all available information on the nature of the disease which was experienced by the community. This constitutes the study of the *acute episode.* The incidence of the disease, as to location of cases, and distribution as to sex, age, race, and varying symptoms and symptom complexes was to be obtained by a canvass of the population. The canvass, performed by public health nurses, was not expected to yield detailed clinical data on the illness. It was therefore planned to have physicians obtain the detailed clinical data by interviewing persons who had been ill during the smog. Further data, available from autopsies and in records of hospitalized patients, were collected by the same physicians.

To this point in the plan, except for the autopsy data, reliance was placed upon the interview of people, and no medical examinations were made. However, to obtain answers to certain other questions, laboratory procedures needed to be used. Thus, a large number of blood examinations were to be made for their influenza antibody titer, to determine the role of influenza in the epidemic; and for the presence of eosinophilia, to evaluate the presence of allergic manifestations in the populace. Chest roentgenograms of a selected series of adults were to be made to evaluate the part which lung disease may have played in the illness.

To determine the extent to which animals were made ill during the episode, a veterinary physician was to be assigned to the study. His duty would be to make inquiry of selected persons who owned animals in the area.

To round out the information on the relationship of various factors to the acute illness, engineers, expert in evaluating housing, were assigned to survey a sample of the local housing; sanitary engineers were assigned to investigate community sanitation.

It would be logically expected that in a community where air contaminants were present in high enough concentrations to have caused acute illness, such contaminants might be present at other times, but in lower concentrations. The influence on health of such concentrations was to be evaluated, since, in addition to such data being of value per se, they might also contribute toward the understanding of the acute episode. For these reasons, studies of *long-term effects* were to be undertaken.

An investigation of the chronic effects of long-continued exposure to fluoride and related substances was to be made by a dental study team who would examine the oral structures of a selected series of persons. Correlative study was to be made of urinary fluoride excretion as well as bone storage of fluoride. Finally, selected groups were to be studied for general morbidity and mortality.

Engineering

The objectives of the engineering part of the investigation were to determine the kinds of contaminants, the amounts produced, and their distribution in the general atmosphere. To obtain information on the kinds of contaminants it was planned to confer with the industrial manufacturers, commercial carriers, and domestic fuel distributors in the Donora area. The information to be obtained from the manufacturing industries consisted of a plan view of the plants showing location and height of stacks, a flow diagram and description of the raw materials, the processes and production figures. Similar information was to be obtained from major industries in the nearby vicinity along the Monongahela River extending from Clairton to Charleroi, Pa. These establishments, although located outside the immediate Donora area, were not precluded as contributors to air pollution within the Donora area.

Detailed information was to be obtained from the railroad and river transportation companies indicating the amount of traffic within the Donora area, the type of motive power used, and the amount of fuel consumed. Community fuel suppliers were to furnish estimates of the amount of fuel used for domestic purposes in the Donora area.

After this preliminary information had been obtained and reviewed, samples were to be collected to determine sources and amounts of contaminants. These data were to provide information on the contaminants discharged and on the pollution load in the community. This sampling at the source of pollution was also to provide information about contaminants which were of such low order of magnitude that when dispersed into the atmosphere they would be difficult to determine with reasonable accuracy.

To obtain an accurate picture of the distribution of the contaminants in the atmosphere, a study was planned of the terrain and community in relation to sources of air pollution so that representative air sampling locations could be selected. Samples were to be collected routinely at these locations for those constituents which were to be selected as being significant, based on the preliminary data and information obtained on the kinds of contaminants. Data on wind speed, temperature, and humidity were to be obtained with each sample.

Meteorological

Record of the various meteorological elements is required if an investigation of atmospheric pollution is to be complete. Without knowing the direction of the wind associated with the source of atmospheric contamination, it is not possible to evaluate air-sampling observations. It was decided, therefore, to study the local behavior of meteorological quantities in the Monongahela Valley, such as wind direction and speed, temperature, relative humidity, and rainfall.

To effect this plan six micrometeorological stations were to be installed across the valley through Donora, and an additional five stations were to be installed along the valley floor. It was thought that the wind data would be useful in following the local movement of the contaminants, the temperature data in measuring the stability or "lid" of the atmosphere and the rain gauges in measuring the cleansing power of the atmosphere during rainy periods.

II. Biological Studies

INTRODUCTION

Biological studies of the problem precipitated by the outbreak of illness, and deaths in the Donora area during the smog of October 1948, were concerned principally with an attempt to describe the acute episode in terms of the incidence and severity of illness in the general population, and to develop a clinical picture of the disease. In addition, an investigation was made of the possible effects on health of continued living in the community, since such effects might well point to the existence of atmospheric contamination of a mild nature, which during the period of prolonged smog might have contributed to the acute outbreak.

In a study of the acute episode, the ideal situation would, of course, be for the investigation to have begun while the illnesses were occurring. This, for many reasons, was not possible, and it is recognized that the data which were collected were frequently modified by the unavoidable delay. Much of the information collected depended upon the memory of persons who were in the Donora area during the smog period, and the delay in reporting might obviously be expected to have resulted in some degree of disappearance from the person's memory of just what had occurred. Therefore, the sequence of events might be altered by the failure of memory, or certain of the milder symptoms of illness might be forgotten. The degree to which this occurred, could not be precisely determined.

It seemed evident, as the investigation progressed, that there were other factors which played a part in the degree of accuracy of reported information. Among these, were the attitudes of the citizenry toward the industrial plant, and pending litigation. The attitude toward the plant varied markedly. Some of the citizens of the community believed that one portion of the plant was culpable for the smog episode, and so, possibly, exaggerated their stories of illness. Others, on the other hand, because they feared the imagined wrath of the plant management, actually minimized their illnesses. It was not possible to evaluate the degree to which these factors balanced each other.

Data on the effects of continued living in the community tended to be more objective in nature although of somewhat limited coverage. Thus, data on morbidity were available from records of industrial sick benefit organizations covering selected individuals. Mortality data were obtained from the Pennsylvania State Department of Health, but records specific for residence were available for the Borough of Donora only, and not for other sections of the area.

The recognition of these limitations does not alter the fact that the various sets of data collected generally served well the purposes for which they were obtained. Thus, the results of a household survey by public health nurses furnish a clear and striking picture of the outbreak of acute illness in the community. These findings together with detailed clinical data collected by our physicians through interviews with persons who had been ill, and through hospital records and autopsies, were useful in giving information on the nature of the illness. Blood examinations and chest X-rays, as well as investigations of animal illnesses during the smog, and of the possible relation of housing to illness, aided in rounding out our knowledge of the disease. Finally, the dental and related investigations for the presence of fluoride effects, together with studies of morbidity and mortality, permit an evaluation of factors possibly associated with long-term living in the community.

THE ACUTE EPISODE

Collection of Data

Wilfred D. David, Mabelle J. Markee, and Emily M. Smith

COMMUNITY SURVEY [1]

To secure information on the incidence and severity of illness that occurred during the October 1948 smog episode in the Donora area, a survey was made of a group of representative households. For purposes of the survey, a household was defined as a group of persons who shared common living arrangements and who ate together. Thus, it might include certain types of roomers.

Visits were made to the households selected and a complete record of all illness and deaths during the smog was obtained in an interview with the housewife or other responsible member of the household. The data collected included, also, a household census, with the name, sex, race, age, marital status, and occupation of each member of the household. The form used for recording these data is shown in figure 1, and the manual describing its use appears in appendix I. The survey was carried on by six registered nurses who had a background in industrial or public health, or both.

The Sample

The population of the Borough of Donora was approximately 12,300 persons living in 3,500 households. In order to have a representative sample of the entire population, every third household was taken from a list prepared by the Borough of Donora Tax Assessor in the Spring of 1947, the selection of the first household having been made at random.

The population of Webster was approximately 1,000 persons living in 250 households, and the households visited were selected in a manner similar to that employed for the Donora Borough using a list of families prepared in November 1948 by a smog investigating committee. A similar list was used to select the households visited in Carroll Township.

The Household Visit

Following newspaper and radio publicity about the project, household visits began December 2, 1948, and continued through March 30, 1949. Each morning the nurses were assigned 15 to 20 households. Although it was not expected that a nurse could visit this many households daily, these numbers were allocated to each nurse since it was anticipated that not all families visited would be at home. A daily record of household assignments was kept in the office. Transportation facilities played a part in the selection of areas visited by the nurses, but every effort was made to have each nurse canvass many areas.

Upon arriving in the home, the nurse introduced herself and told the purpose of the visit. She explained that all the information received would be held confidential. The interview was generally opened with the question, "Were you affected by the October smog?" This naturally led into the discussion of previous and present health status, and to the other data required. All data were recorded as they were obtained in the homes.

During the early part of the survey, the nurse had the responsibility of selecting from her house visits, persons who were to be interviewed by the physicians of the study team. This selection was based on severity of illness, and the more severely ill were chosen. These persons were given appointments for interviews.

When the day's household visits were finished, the nurses reported to the office and the filled-in forms were checked for completeness. All forms were reviewed and the following items were tabulated: (*a*) All people affected by the smog; (*b*) all deaths during and after the smog; and (*c*) all affected animals and pets. Finally, the households for which data were completed were spotted on a large street map of the area.

Techniques for developing uniformity of performance in household visits by the nursing personnel were planned and carried out. As the survey progressed the items of the survey forms were frequently discussed, with the result that the nurses used essentially identical techniques, and differences in the data collected were considered of minor consequence.

During the survey period, the average number of completed household visits per day was 6.75 per nurse. This did not include the house visits which could be classified as "not at home," "not found," or "not listed in the sample." Of the 1,451 families originally listed as the sample to be studied, complete data were obtained for 1,308. Figure 2 shows the distribution of the studied households. The remainder were not completed for various reasons, among which the more important were, "address not located," "no one ever at home," and "removed from area."

In some instances repeated visits had to be made before the forms were completed. In a few instances the same houses were visited as many as eight times, a procedure naturally quite time-consuming. Another factor which affected the

[1] Participants: Katharine A. Lembright, Walborg S. Wayne, Helen Enright, and Mary Matthews.

Nurse interviewing a member of a Donora area household.

Physician interviewing a resident who had been ill during the smog period.

Dentist performing an oral examination in a Donora plant.

DONORA STUDY

HISTORY OF SMOG ILLNESS BY HOUSEHOLD CANVASS

Date ______ Household No. ______ Telephone No. ______ Case No. ______
Name ______ Family physician ______
Name of informant ______ Relation ______
Age ______ Sex: M ______ F ______ Color: W ______ N ______ Marital status: S ____ M ____ W ____ D ____

OCCUPATIONAL HISTORY

	Plant	Location	Department	Occupation	Years
1					1949 to 19__
2					19__ to 19__
3					19__ to 19__
4					19__ to 19__

RESIDENCE HISTORY

Present address ______ 1949 to 19__
Previous address ______ 19__ to 19__
Previous address ______ 19__ to 19__
Previous address ______ 19__ to 19__

PREVIOUS HEALTH STATUS

Asthma ______ Heart disease ______ Chronic bronchitis ______ Tuberculosis ______
Sinusitis ______ Rundown condition ______ Other (specify) ______
Doctor's name ______
Were you ever affected by smog in Donora: Y ____ N ____ When? ______
Were you in Donora area October 28–31: Y ____ N ____
At home: Y ____ N ____ Where: ______
Affected by smog of October 28–31: Y ____ N ____ Date of onset ______
Symptoms: Cough: ______ Productive ______ Nonproductive ______ Constriction of chest ______
Nausea ______ Vomiting ______ Headache ______ Dyspnoea ______ Orthopnoea ______
Cyanosis ______ Fever ______ Smarting of eyes ______ Lacrimation ______
Soreness of throat ______ Nasal discharge ______ Other ______
How many days ill: 0 ____ 1 ____ 2 ____ 3 ____ 4 ____ 5 ____ More ____
Attended by:
Hospital: Y ____ N ____ Name of hospital: ______
Did you receive oxygen treatment: Y ____ N ____ Not known ____ By whom? ______
Any symptoms at present: Cough ______ Constriction of chest ______ Dyspnoea ______
Soreness of throat ______ Other ______
Did you ever have pneumonia: Y ____ N ____ When: (year) ______
How many colds have you had in 1948; 0 ____ 1 ____ 2 ____ 3 ____ 4 ____ 5 ____
How many colds per year did you have before coming to Donora: 0 ____ 1 ____ 2 ____ 3 ____ 4 ____
House: G ____ F ____ P ____
Remarks: ______
______
______
______
______
Animals: ______ Effect: ______

Signature ______

FIGURE 1.—*Form used in community survey.*

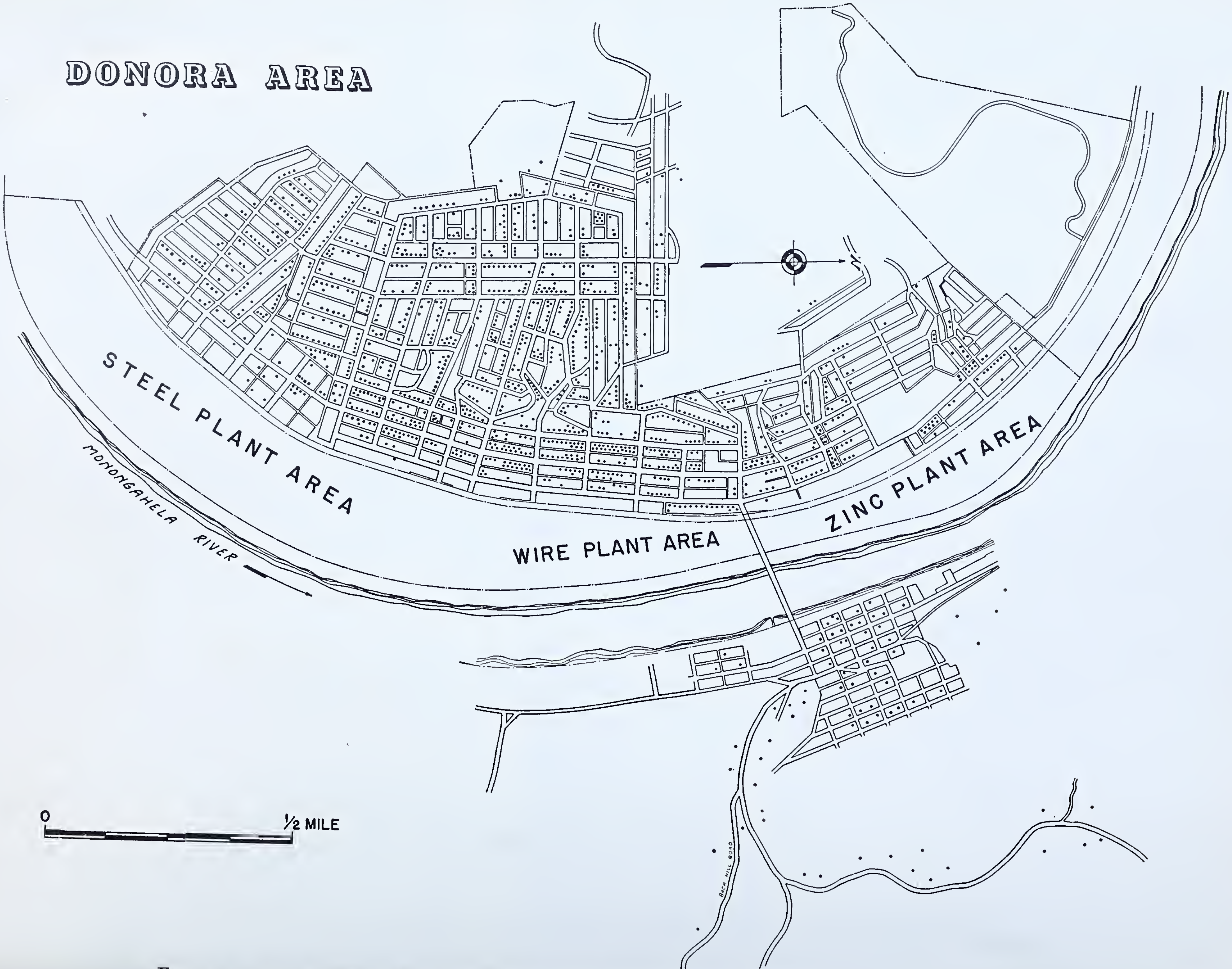


FIGURE 2.—*Map showing households visited by nurses in community survey. Each dot represents one household.*

time necessary to collect the data on any one family depended on the size of the family. Table 1 shows the distribution by number of persons in the households visited.

TABLE 1.—*Distribution of households in community survey according to size of household*

Number of persons in household	Households		Persons	
	Percent	Number	Percent	Number
Total	100. 0	1, 308	100. 0	4, 613
1	7. 7	101	2. 2	101
2	22. 7	297	12. 9	594
3	25. 2	330	21. 5	990
4	21. 6	283	24. 5	1, 132
5	10. 8	141	15. 3	705
6	6. 0	79	10. 3	474
7	2. 9	38	5. 8	266
8	1. 4	18	3. 1	144
9	. 7	9	1. 7	81
10	. 6	8	1. 7	80
11	. 2	2	. 5	22
12	. 2	2	. 5	24

INTERVIEWS BY PHYSICIANS[2]

Since there was a lack of adequate data on the occurrence of illness and a difference of local medical opinion concerning the clinical picture of the acute episode at the time of our entry into the investigation, it was necessary to make a thorough study of persons who had been ill during the smog. The purpose of this study was twofold: (*a*) To obtain information about the clinical syndrome or syndromes, and (*b*) to show the relationship of the syndrome or syndromes to the following factors—age, sex, race, residence, time of onset, previous health status, and source and concentration of air pollutants.

To obtain the pertinent information, a selected group of affected persons was interviewed by physicians of the study team, and blood samples were taken of the persons interviewed and of a control group. In addition, supplemental information was collected on the more severely affected. Thus, local physicians were interviewed concerning their findings and therapy. Hospital records were reviewed for a large series of hospitalized persons. Relatives and friends were visited for the purpose of obtaining any additional information about the ill persons. This last was especially of value in respect of persons who had died. To round out our understanding of the illness, information was also obtained from every other possible source, including local pharmacists, clergymen, police officers, undertakers, and others.

Interviews of Ill Persons

For recording information in the interviews of ill persons, a form (fig. 3), and a manual (appendix II) describing its use, were prepared. The form was prepared after interviewing several ill persons, conferring with local physicians, and consulting with others concerned with the problem. The personnel who obtained the information consisted of physicians well versed in performing this type of work.

[2] Participant: David Zinke.

The interviews were conducted during a period of approximately five weeks, and were concurrent with the early part of the household survey. During this time 516 interviews were completed. An early problem was to find reliable sources of names of persons who were ill in late October. Since time was important, a readily available fund of names was necessary. The four sources used were the nurses' household survey, the Donora Borough survey,[3] a local physician's list, and voluntary cases.

In the nurses' survey, the nurses were instructed to refer to our physicians all names of more severely ill persons encountered. Appointments for interviews with the physicians were made during the initial home visits. The completed survey made by the Borough of Donora was reviewed, and the names of persons allegedly ill during the smog, and who had been attended by a physician, were recorded. Appointments for interviews were made with these persons by a special clerk whose home was in Donora and who had a knowledge of several of the foreign languages spoken in the district. The clerk, after extracting from the central card index the name and address of the person with whom the appointment was to be made, communicated directly with him either by telephone or by home visit. Appointment cards were used whenever possible.

In addition to the group of persons for whom appointments were made, there was a small group of smog-affected persons who volunteered to appear for interview. The reasons for their appearance for interview with the physician varied greatly.

The interviews were held in a private room at the Borough Building in Donora, which was centrally located. Of the total number of appointments made, 515 were made by the clerk, and 73 by the nurses. Of these, 393 (76.3 percent) of the clerk's appointments were kept by the citizens, and 64 (87.7 percent) of the nurses' appointments were kept. In addition, there were 59 people who appeared for interview on their own initiative.

After obtaining certain preliminary information, the technique of the interview consisted of allowing the informant to talk at length about what happened to him as a result of the smog episode. At the beginning, interruptions by the physician were kept at a minimum and used merely to clarify certain points and to keep the person talking about himself. As the interview progressed, questions were asked to fill in gaps in the information. For example, it was necessary to ask many questions on symptoms and their sequence. An effort was made by the physician to record separately the information about symptoms given spontaneously and that elicited by direct questioning.

Blood Samples

After the interview was over, the person was ushered into a laboratory, set up in the Borough Building, where a medical technician obtained blood specimens by puncture of the antecubital vein. Two milliliters of blood were placed in each of two stoppered test-tubes and were sent to the National Institutes of Health for study of the influenza anti-

[3] The Donora Borough officials made a canvass of every household chiefly for the purpose of obtaining the incidence of alleged smog illness.

DONORA STUDY

CLINICAL DATA ON AFFECTED PERSONS

Date ______ Household No. ______ Telephone No. ______ Case No. ______
Source: Borough Survey ______ Nurses' Survey ______ Physicians' ______ Voluntary ______ Other______
Name ______ Address ______
(Webster, Donora, other)
Informant (if not self) ______Relationship to patient ______
Birthplace ______ Age ____ M ____ F ____ Color W ____ N ____ M __ S __ W __ D __
Residence History: Present Address ______ Yrs. 1949 to 19____
Previous Address ______ 19____ to 19____
Previous Address ______ 19____ to 19____

OCCUPATIONAL HISTORY

	Plant	Location	Occupation	
1.				Yrs. 1949 to 19____
2.				19____ to 19____
3.				19____ to 19____
4.				

SMOG ILLNESS (OCTOBER 1948)

Onset: Gradual ____ Sudden ____ Location ______ Time: A. M. ____ P. M.____
Wed. ____ Thurs. ____ Fri. ____ Sat. ____ Sun. ____ Mon. ____ Other ______ Activity at time of onset______
______
Others at same location: Male ____ Female ____ How many became ill: Male ____ Female ____

SYMPTOMS	Own	Sugg.	Duration	SYMPTOMS—Continued	Own	Sugg.	Duration
Eye irritation				Chest discomfort:			
Nasal discharge				Retrosternal burning			
Odor: foul				Retrosternal pressure			
other				Costal margin			
Taste: acid				Parasternal pressure			
metallic				Muscle soreness			
Sore throat				Epigastric distress			
Dry throat				Nausea			
Cough: productive				Vomiting			
nonproductive				Anorexia			
Color of sputum				Abdominal pain			
Dyspnoea				Abdominal pressure			
Orthopnoea				Ankle oedema			
Wheezing				Cyanosis			
Palpitation				Headache			
Fever				Weakness			
Chills				Other			

Medical treatment: Yes ____ No ____ Physician______ Address ______
Hospital______ Days ill______
Past illness: Bronchial asthma ____ Chronic bronchitis ____ Sinusitis ____
Heart disease ____ Pneumonia ____ Tuberculosis ____ Other ______
Does smog aggravate or bring on attacks of the above: Yes ____ No ____ Which one: ____ When: 19____

ALLERGIC HISTORY

	Self	Father	Mother	Siblings	Children
Skin rash					
Urticaria					
Hay fever					
Asthma					

Signature ______

FIGURE 3.—*Form used in interviews of persons ill during the smog.*

body titer. One milliliter of blood added to 9 milliliters of distilled water, contained in a test tube, was utilized for spectrographic study. Finally, the technician prepared two blood smears stained with Wright's stain for study of the differential leukocyte count. One hundred white blood cells were counted in each case, and the differential pattern recorded. Control studies were performed on a group of individuals who had not been ill during the smog.

The Acute Illness

Harry Heimann, Wilfred D. David, and Rosedith Sitgreaves

THE COMMUNITY EXPERIENCE

Results of the community survey covering one-third of the households in the Donora area were used to describe the impact of the smog of October 1948 upon the health of the community. Households in the survey were preselected by means of a sampling plan designed to furnish data which might be validly used as characteristic of the community as a whole. In the analysis, rates and percentages based on the sample are discussed as applying to the corresponding total group in the community; population estimates were determined by multiplying appropriate numbers for the sampled group by three. Sampling variances for the percentages and estimated population figures are not presented in this report. However, the sampling plan was so designed that the various estimates are generally determined within five percent at the outside, that is, with a coefficient of variation of less than two percent.

Donora Area as a Whole

Population characteristics.—The total population of the Donora area, as estimated from the sample, was 13,839 persons. Of these, 7,104 or 51 percent were males and 6,735 or 49 percent were females. Nonwhite persons constituted 8.5 percent of the total for each sex, and were Negro except for a negligible number of Chinese. Corresponding census data [4] for the State of Pennsylvania reveal that in 1940 the population of the State was almost equally divided between males and females, nonwhite persons constituting 5 percent of the total. It seems reasonable that the nonwhite population of an industrial community like Donora would be relatively greater than that of the State as a whole.

The age distribution of persons in the area is given in table 2 by sex and race. Of the total group, approximately 30 percent were under 20 years of age, 40 percent were 20–44 years of age, and the remaining 30 percent were 45 years of age and over. The median age for both males and females was 31, but the proportion of females 55 years of age and over was somewhat less than the corresponding proportion for males. For each sex, the median age for nonwhite persons was less than 30 with relatively fewer nonwhite persons at ages 55 and over. The age distribution compares favorably with 1940 census data for the State of Pennsylvania which indicated that the median age was 29 years for both white and nonwhite persons. Further, no valid differences were found in the age distribution of the Donora Borough population compared with that of towns of similar size, both within the valley (Monessen, Canonsburg) and with towns outside the valley (Greensburg, Butler, and Uniontown).

TABLE 2.—*Age distribution of persons in Donora area, by sex and race*

Age in years	Total	Sex and race			
		White males	Nonwhite males	White females	Nonwhite females
	Percent				
All ages	100. 0	100. 0	100. 0	100. 0	100. 0
Under 6	10. 7	11. 1	12. 4	9. 8	13. 6
6–19	20. 6	20. 9	25. 2	19. 4	24. 6
20–34	25. 8	23. 7	20. 8	28. 4	26. 7
35–44	12. 9	12. 7	9. 9	13. 5	12. 0
45–54	11. 8	11. 1	19. 8	11. 6	13. 6
55–64	11. 5	13. 2	8. 9	10. 5	5. 8
65 and over	6. 7	7. 3	3. 0	6. 8	3. 7
	Number [1]				
All ages	13, 839	6, 498	606	6, 162	573
Under 6	1, 476	720	75	603	78
6–19	2, 850	1, 359	153	1, 197	141
20–34	3, 570	1, 542	126	1, 749	153
35–44	1, 785	822	60	834	69
45–54	1, 638	723	120	717	78
55–64	1, 587	855	54	645	33
65 and over	933	477	18	417	21

[1] Numbers were determined by multiplying corresponding numbers for the sampled group by 3.

Table 3 gives the distribution of persons in the area according to occupational status, specific for sex and race. It will be observed that over 35 percent of the total group were gainfully employed, not quite 30 percent were housewives, and 30 percent (corresponding essentially to the group of persons under 20 years of age) were school and preschool children. Of the gainfully employed, more than 85 percent worked in the area and of these, some two-thirds were employed in the local steel and zinc plants. Females constituted less than 20 percent of the total gainfully employed and worked principally in clerical, and trade and service occupations.

Incidence of smog affection.—A total of 5,910 persons or 42.7 percent of the total population of the Donora area experienced some affection from the smog of October 1948, the

[4] U. S. Bureau of Census: Sixteenth Census of the United States, 1940. Population. Vol. 4: Characteristics by Age. Part 4: Ohio-Wyoming. U. S. Government Printing Office, Washington (1943). P. 205.

degree of affection varying from slight to extremely severe. Affected persons were classified as mildly, moderately, or severely affected, depending upon the number and kind of symptoms reported, the length of disability, the need for medical attention as determined by the successful or unsuccessful attempt to obtain a physician, and the outcome of illness. Smarting of eyes, lacrimation, nasal discharge, choking (that is a sense of constriction of the throat), sore throat, nonproductive cough, nausea without vomiting, headache, weakness, and aches and pains, were considered "mild" symptoms; productive cough, constriction of chest (defined as a sense of tightness or feeling of pressure in the chest), dyspnoea without orthopnoea, vomiting, and diarrhea, were considered "moderate" symptoms; orthopnoea was considered a "severe" symptom. The following table shows the classification scheme used:

Number and kind of symptoms	Additional factors for classifying degree or severity of illness		
	No period of disability; no medical care needed; no symptoms still present at time of survey	Disability of 1 to 3 days; and/or medical care needed; and/or symptoms still present at time of survey	Disability of 4 days or longer
1 to 3 "mild" symptoms	Mild	Moderate	Moderate.
4 or more "mild" symptoms	Moderate	Moderate	Severe.
1 to 3 "moderate" symptoms with or without "mild" symptoms.	Moderate	Moderate	Severe.
4 or more "moderate" symptoms with or without "mild" symptoms.	Moderate	Severe	Severe.
Orthopnoea with or without other symptoms	Moderate	Severe	Severe.

Table 3.—*Distribution of persons in Donora area according to occupational status, by sex and race*

Occupational status	Total	Sex and race			
		White males	Nonwhite males	White females	Nonwhite females
	Percent				
Total	100.0	100.0	100.0	100.0	100.0
Gainfully employed	37.6	60.6	57.4	14.1	8.4
Donora steel and zinc plants	21.7	40.4	46.0	1.5	0
Other employment in Donora area	10.9	13.1	6.4	9.3	6.8
Other employment out of Donora area	5.0	7.1	5.0	3.3	1.6
Housewife	28.5			58.9	55.0
School child	18.6	19.5	23.3	16.8	23.0
Preschool child	10.5	10.9	12.4	9.7	12.6
Retired	2.3	4.7	2.5	0	0
Other	2.5	4.3	4.4	.5	1.0
	Number [1]				
Total	13,839	6,498	606	6,162	573
Gainfully employed	5,205	3,939	348	870	48
Donora steel and zinc plants	3,003	2,628	279	96	0
Other employment in Donora area	1,503	852	39	573	39
Other employment out of Donora area	699	459	30	201	9
Housewife	3,942			3,627	315
School child	2,574	1,269	141	1,032	132
Preschool child	1,452	705	75	600	72
Retired	321	306	15	0	0
Other	345	279	27	33	6

[1] See footnote 1, table 2.

In a relatively small number of cases where additional information appeared to invalidate the scheme as given, the physician independently noted the severity of affection on the basis of all reported data. According to this classification, 2,148 persons in the Donora area were mildly affected, 2,322 were moderately affected, and 1,440 were severely affected, the numbers representing, respectively, 15.5, 16.8, and 10.4 percent of the exposed population.

Approximately one-third of all affected persons reported onset of affection on Friday evening, October 29, between 6 p. m. and midnight. Over half of the affected persons became ill at home; about 20 percent reported onset while in the open air, and some 12 percent became ill at work. Fifteen percent of the affected persons were seen by a physician, and one percent was hospitalized. Of a selected group of more or less severely affected persons interviewed by the physicians, it was found that approximately 25 percent were at rest when onset of affection occurred.

Incidence rates [5] by sex and race.—The percent of persons of indicated sex and race in the Donora area reporting affection from the October smog, is given in table 4 according to degree of affection.

Table 4.—*Incidence of smog affection among persons of indicated sex and race in Donora area*

Sex and race	Percent of persons of indicated sex and race reporting affection from smog			
	Total	Degree of affection		
		Mild	Moderate	Severe
Total	42.7	15.5	16.8	10.4
White males	43.4	15.2	17.6	10.6
Nonwhite males	39.1	9.4	15.3	14.4
White females	42.9	16.8	16.4	9.7
Nonwhite females	36.1	11.5	13.1	11.5

[5] The term "incidence rate" is used in the present study to denote the percent of exposed persons reporting an indicated degree of affection from smog; that is, the number of persons becoming affected per 100 persons exposed.

An examination of table 4 reveals that total rates ranged from 36.1 for nonwhite females to 43.4 for white males. Relatively little sex difference is shown in male and female rates for each degree of affection and race. For both males and females, the total incidence rate was higher among white persons, but incidence of severe affection was higher in the nonwhite group. However, race differences are not significant, and since the total number of nonwhite persons is relatively small, data for white and nonwhite persons will henceforth be combined.

Incidence rates by sex and age.—The percent of persons of indicated sex and age reporting affection from smog is given in table 5 according to degree of affection. Rates for males and females combined are presented graphically in figure 4, while rates by sex are shown in figure 5.

An examination of figure 4 reveals a generally increasing trend with age in the total incidence of affection from smog, the percent of persons affected rising from 16 percent of the children under 6 years of age to 60 percent, or almost two-thirds, of all persons 65 years of age and over. Moreover, there is a marked change with age in the composition of the affected group in respect of severity of affection. Thus, the percent of persons mildly affected shows relatively little change with age but represents a progressively smaller proportion of the total percent of affected persons. While only about one-tenth of affected persons under 6 years of age were severely affected, almost one-half of affected persons 65 years of age and over were in the severely affected group, the corresponding incidence rates ranging from 2 to almost 30 percent of the respective population groups. The percent of persons moderately affected tended to increase with age up to the age group 30–34 years, remaining relatively constant thereafter. It should be noted, in this connection, that there appears to be no difference between the affected and nonaffected group at the various age levels for length of residence in the area.

It will be observed in figure 5 that the age pattern of incidence rates for each sex was similar to that observed above for the two sexes combined, and that no consistent sex differences were shown.

Incidence rates by occupation and age.—Incidence rates for the adult population of the Donora area are given in table 6 according to occupational status and degree of affection. Because of observed age variation, rates are shown for each of three broad age groups as well as for adults of all ages.

It is of interest to observe in table 6 that some degree of affection from the smog of October 1948 was reported for one-half of all adults in the Donora area; about 16 percent of the adult population were mildly affected, 20 percent were moderately affected, and 14 percent were severely affected. Rates for the three broad age groups follow the general pattern of age variation observed above; particular reference is made, however, to the fact that the incidence rate for severe affection among adults under 35 years of age is doubled for the age group 35–54 years and redoubled for the group 55 years of age and over.

With only a few minor exceptions, rates according to occupational status for a given age group and degree of affection reveal no significant variation. Thus, for all ages, and for persons under 55 years of age, relatively low incidence rates are recorded for persons employed out of the Donora area. This is not unexpected since these persons had a smaller exposure time in the area. More noteworthy, perhaps, is the fact that persons 55 years of age and over who were employed out of the area experienced incidence rates similar in magnitude to rates for all persons in this age group. It appears, therefore, that the factor of susceptibility to smog affection revealed for persons 55 years of age and over was of sufficient influence to outweigh the smaller exposure time in the area.

Onset of affection.—About 60 persons in the area experienced ill effects, presumably from smog, during the two days preceding S-day.[6] Some 750 persons reported onset of affection in the 54-hour period beginning with S-day and

[6] The term "S-day" is applied to Wednesday, October 27, 1948, the first day of severe smog. Days numbered *1, 2, 3, 4, 5, 6,* refer to days after S-day.

TABLE 5.—*Incidence of smog affection among persons of indicated sex and age in Donora area*

Age in years	Percent of persons of indicated sex and age reporting affection from smog											
	Both sexes				Males				Females			
	Total	Degree of affection			Total	Degree of affection			Total	Degree of affection		
		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe
All ages	42.7	15.5	16.8	10.4	43.0	14.7	17.4	10.9	42.4	16.4	16.1	9.9
Under 6	15.9	9.8	4.3	1.8	17.8	12.5	3.4	1.9	13.7	6.6	5.3	1.8
6–12	29.6	15.7	11.0	2.9	27.1	15.7	8.2	3.2	32.7	15.7	14.4	2.6
13–19	27.3	15.2	9.6	2.5	25.6	14.8	8.5	2.3	29.0	15.7	10.6	2.7
20–24	31.2	13.9	13.1	4.2	31.1	14.1	11.9	5.1	31.3	13.7	14.3	3.3
25–29	40.3	18.8	14.9	6.6	39.2	15.5	16.0	7.7	41.1	21.4	14.0	5.7
30–34	48.0	17.1	22.8	8.1	50.0	14.6	26.3	9.1	46.2	19.3	19.7	7.2
35–39	52.3	19.5	23.7	9.1	53.9	16.2	29.9	7.8	50.6	22.8	17.3	10.5
40–44	54.9	22.2	21.8	10.9	55.9	22.1	23.6	10.2	54.0	22.3	20.2	11.5
45–49	57.1	17.8	24.7	14.6	57.5	17.7	24.8	15.0	56.7	17.9	24.6	14.2
50–54	59.4	18.9	22.0	18.5	60.9	14.1	27.3	19.5	58.0	23.7	16.8	17.5
55–59	58.1	13.7	24.0	20.4	60.5	14.7	22.9	22.9	55.1	12.6	25.2	17.3
60–64	63.3	11.0	22.9	29.4	63.0	10.3	24.0	28.7	63.6	12.1	21.2	30.3
65 and over	59.8	10.6	20.3	28.9	60.6	10.9	21.2	28.5	58.9	10.3	19.2	29.4

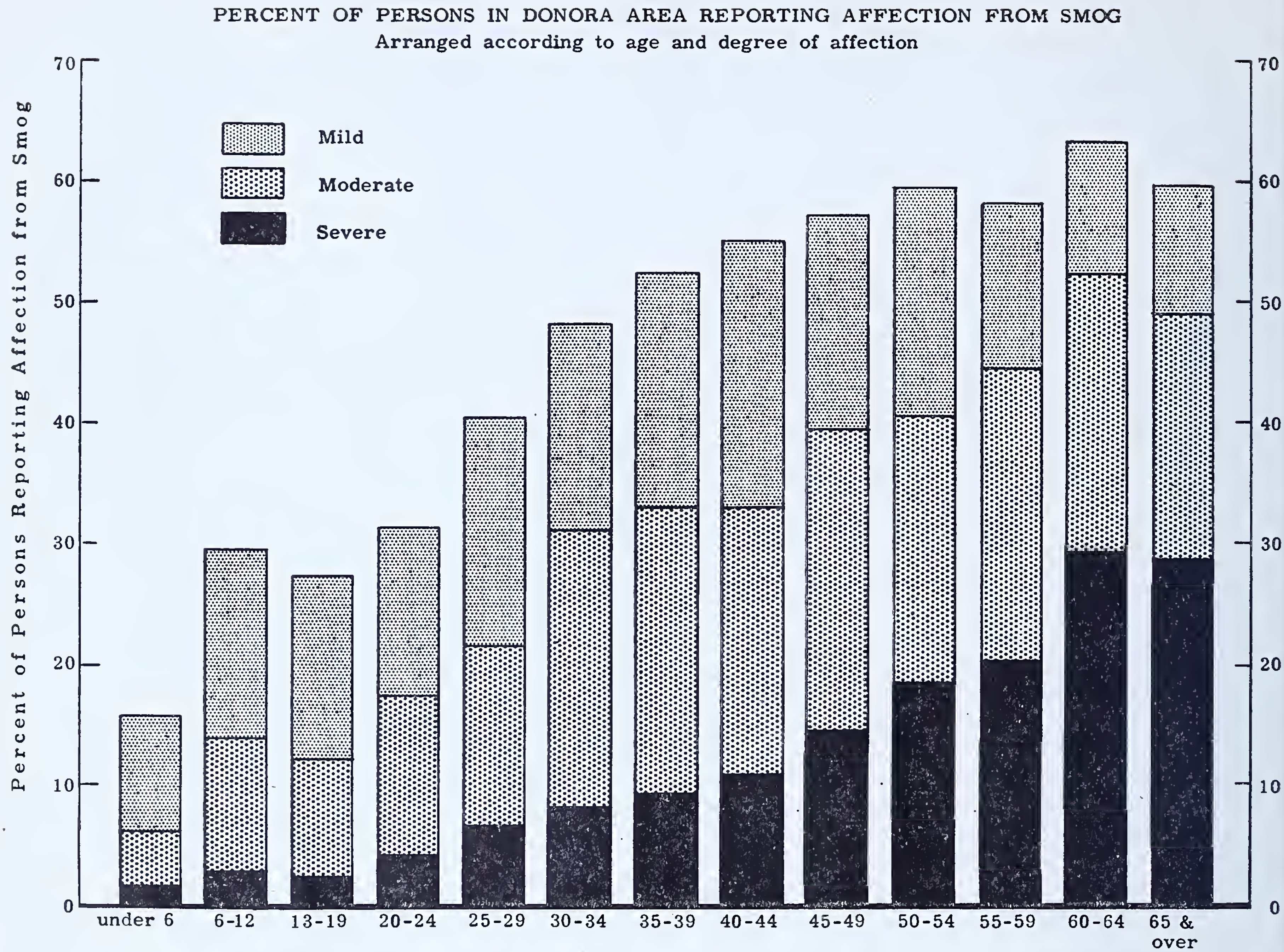


FIGURE 4.—*Incidence of smog affection among persons of indicated age in Donora area.*

TABLE 6.—*Incidence of smog affection among adults of indicated age and occupational status in Donora area*

Occupational status	Percent of adults of indicated age and occupational status reporting affection from smog															
	All ages				Age in years											
					Under 35				35–54				55 and over			
	Total	Degree of affection			Total	Degree of affection			Total	Degree of affection			Total	Degree of affection		
		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe
Total (adults)	50. 5	16. 5	20. 4	13. 6	39. 6	17. 0	16. 6	6. 0	55. 7	19. 5	23. 1	13. 1	60. 2	11. 8	22. 2	26. 2
Gainfully employed	49. 6	15. 9	21. 1	12. 6	38. 2	14. 7	16. 9	6. 6	56. 4	18. 7	25. 2	12. 5	60. 6	13. 0	22. 5	25. 1
Donora steel and zinc plants	52. 2	16. 1	22. 6	13. 5	41. 0	15. 4	18. 3	7. 3	58. 4	17. 8	27. 1	13. 5	60. 7	14. 1	22. 4	24. 2
Other employment in Donora area	50. 1	16. 4	20. 9	12. 8	39. 3	15. 5	17. 0	6. 8	56. 0	20. 1	24. 5	11. 4	60. 4	11. 7	22. 6	26. 1
Other employment out of Donora area	36. 9	13. 7	15. 0	8. 2	29. 2	11. 8	13. 2	4. 2	45. 3	20. 3	15. 6	9. 4	60. 0	8. 0	24. 0	28. 0
Housewife	52. 1	18. 2	19. 7	14. 2	43. 1	20. 4	17. 3	5. 4	55. 3	20. 6	20. 8	13. 9	59. 8	11. 9	21. 5	26. 4
Retired	55. 1	7. 5	21. 5	26. 1	----	----	----	----	----	----	----	----	55. 1	7. 5	21. 5	26. 1
Other	43. 5	16. 5	14. 8	12. 2	31. 2	16. 9	10. 4	3. 9	41. 7	25. 0	8. 3	8. 4	80. 8	11. 5	30. 8	38. 5

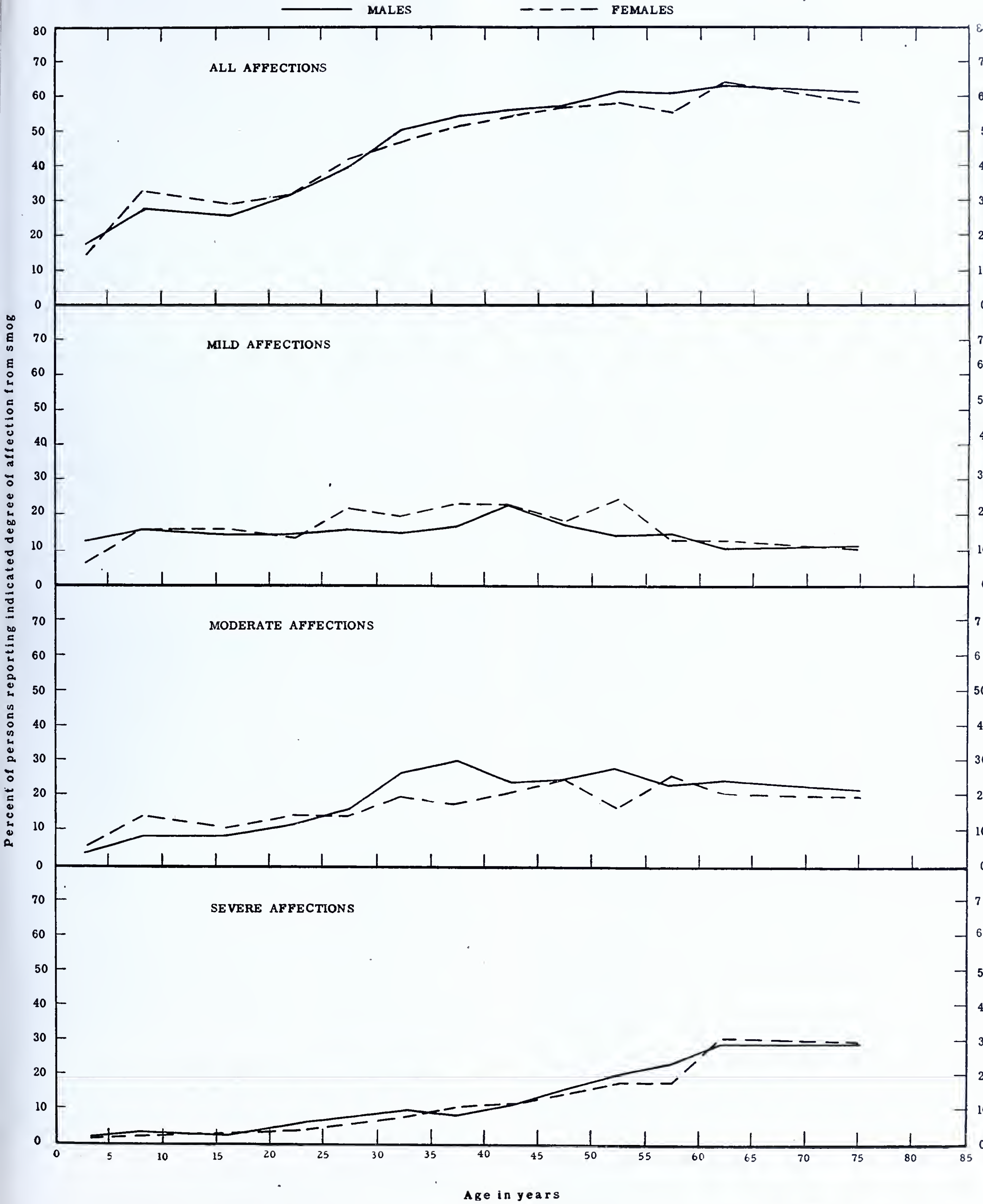


FIGURE 5.—*Age variation in incidence of smog affection among males and females in Donora area.*

ending at 6 a. m. on the second day after S-day; 1,600 more reported onset of affection in the 12-hour period between 6 a. m. and 6 p. m. on day No. 2 (that is, the second day after S-day); and 2,100 became ill in the 6 hours between 6 p. m. and midnight of that day. Approximately 1,000 persons reported onset of affection in the 12 hours following midnight of day No. 2 and the remaining 400 became ill after noon of day No. 3.

Data available from interviews of affected persons conducted by the physicians indicate that about 60 percent of the onsets were sudden and about 40 percent were gradual. In general, affection beginning before day No. 2 tended to be associated with a more gradual type of onset.

Figure 6 presents graphically the cumulative percent of persons affected during a time period beginning two days before S-day and ending at times ranging from one day before S-day to day No. 6. Percentages are shown by degree of affection for persons of all ages and those in each of seven age groups. For a given age group and degree of affection, the series of percentages is the percent of exposed persons affected, for example, by the end of day No. 1, or before 6 a. m. on day No. 2. Each series is nondecreasing since the percent of persons affected before 6 p. m. on day No. 2 includes persons affected before 6 a. m. on the same day. It should be noted that not all of the persons affected in the first few days of the period necessarily remained ill throughout the entire time. However, no person was counted as having more than one onset of affection.

An examination of figure 6 reveals a number of interesting relationships which may be briefly summarized as follows.

(1) By 6 p. m. of day No. 2 the percent of persons affected ranged from 6 for persons under 6 years of age to over 25 for persons 55 years of age and over. The percent for persons of all ages was 18.

(2) These percentages increased markedly during the 6-hour period from 6 p. m. until midnight of day No. 2. For persons in age groups under 35 years, the percent of persons affected doubled in that time. Among persons in older age groups, the percent affected increased to values ranging from 38 to 48 of every 100 persons exposed. By midnight of day No. 2, one out of every three persons in the Donora area had experienced some affection from the smog, this proportion being almost twice the proportion of persons affected up to 6 p. m. that evening.

(3) The greatest relative increase during the period from 6 p. m. to midnight of day No. 2 occurred in the percent of persons mildly affected; the smallest relative increase occurred in the percent of persons severely affected. Among persons of all ages, the percent of persons mildly affected doubled in the 6 hours, increasing from 5.7 to 11.7 percent. The percent of persons moderately affected increased from 6.7 to 12.7, while the percent of persons severely affected rose from 5.1 to 8.2.

(4) About 25 percent of all affections began in the period ending at noon on day No. 2, while 75 percent had begun by midnight of that day. For all ages, and for most of the age groups, approximately one-half of the severe affections began before 6 p. m. on day No. 2, while less than 40 percent of the mild affections had begun by that time.

Frequency of symptom complexes.—Symptoms reported by affected persons were classified as upper respiratory, lower respiratory, gastrointestinal, and "other," according to the following classification: upper respiratory symptoms—smarting of eyes, lacrimation, nasal discharge, choking, and sore throat; upper *or* lower respiratory symptoms—cough and constriction of chest; lower respiratory symptoms—dyspnoea, orthopnoea, and cyanosis; gastrointestinal symptoms—nausea, vomiting, and diarrhea; "other" symptoms—headache, fever, weakness, and aches and pains. The symptoms of smarting of the eyes and lacrimation were included with the group of upper respiratory symptoms because they indicated an irritant effect of exposed mucous membranes.

Table 7 gives, for all ages and each of seven age groups, the percent of persons reporting one or more symptoms of

TABLE 7.—*Frequency of symptom complexes among persons of indicated age in Donora area*

Age in years	Percent of persons of indicated age reporting 1 or more symptoms of given complex				
	All symptoms	Upper respiratory symptoms	Lower respiratory symptoms	Gastrointestinal symptoms	Other symptoms
All ages	42. 7	39. 2	37. 2	14. 5	19. 4
Under 6	15. 9	14. 6	13. 2	2. 6	1. 2
6–19	28. 5	24. 9	23. 4	7. 1	10. 7
20–34	40. 3	37. 1	34. 3	11. 8	18. 8
35–44	53. 4	49. 1	46. 2	18. 3	23. 2
45–54	58. 2	52. 9	49. 5	23. 3	29. 1
55–64	60. 5	57. 1	56. 7	26. 3	31. 4
65 and over	59. 8	55. 9	57. 2	23. 8	31. 8

the indicated syndrome, regardless of other symptoms reported. Thus a person reporting sore throat, dyspnoea, nausea, and headache, is included in each of the four classifications. Persons reporting cough or constriction of chest are classified as reporting both upper and lower respiratory symptoms.

Almost 40 percent of all persons in the Donora area reported the presence of upper respiratory symptoms during the smog period, 37 percent reported one or more lower respiratory symptoms, 15 percent experienced gastrointestinal symptoms, and 19 percent reported the presence of one or more "other" symptoms. If these percentages are considered in relation to the 42.7 percent of the population reporting some affection from the smog, that is, the group reporting one or more symptoms regardless of type, it will be seen that over 90 percent of the affected group reported upper respiratory symptoms, 87 percent reported lower respiratory symptoms, 34 percent reported gastrointestinal symptoms, and 45 percent of the affected group reported "other" symptoms.

For each of the syndromes, the percentage of persons reporting one or more of the indicated type of symptom tends to increase with age, the increase being more marked for age groups under 55 years. For each age group, persons reporting upper respiratory symptoms represent some 90 percent of all affected persons of that age group, while the

TABLE 8.—*Frequency of individual symptoms among persons of indicated age in Donora area*

Symptom	Percent of persons of indicated age reporting specified symptom							
	All ages	Under 6	6–19	20–34	35–44	45–54	55–64	65 and over
Upper respiratory symptoms:								
Smarting of eyes	12.3	2.2	7.7	12.6	15.1	17.2	17.0	18.6
Lacrimation	8.0	3.0	4.7	7.4	9.9	12.3	10.6	12.5
Nasal discharge	6.6	3.5	4.8	5.4	7.4	9.3	10.4	8.7
Choking	2.3	.6	.8	1.6	3.5	4.2	3.8	4.5
Sore throat	23.1	5.3	14.8	23.8	30.9	32.8	31.6	27.7
Upper or lower respiratory symptoms:								
Cough	33.1	12.8	22.0	30.9	41.5	44.0	47.3	47.6
Nonproductive	20.2	10.4	17.5	17.6	24.2	27.5	24.8	25.4
Productive	12.9	2.4	4.5	13.3	17.3	16.5	22.5	22.2
Constriction of chest	21.5	3.0	8.8	17.6	27.7	32.8	41.6	37.9
Lower respiratory symptoms:								
Dyspnoea without orthopnoea	12.9	2.2	6.0	11.4	17.0	18.1	24.0	20.9
Orthopnoea	8.4	1.4	1.5	5.6	7.4	14.7	19.5	22.8
Cyanosis	1.0	0	.2	.3	.7	.9	3.0	4.5
Gastrointestinal symptoms:								
Nausea without vomiting	7.1	.2	3.4	6.6	8.7	10.8	13.4	11.3
Vomiting	7.4	2.4	3.7	5.2	9.6	12.5	12.9	12.5
Diarrhea	.1	0	0	.2	.2	0	0	0
Other symptoms:								
Headache	17.0	.6	9.4	17.0	20.8	26.0	26.8	26.7
Fever	2.6	.8	2.1	1.8	2.4	3.1	5.9	4.5
Weakness	1.8	0	.4	1.5	2.5	2.6	3.8	4.2
Aches and pains	1.9	.2	.7	1.3	2.7	3.3	3.2	4.5

percent of affected persons reporting lower respiratory symptoms increases with age from 83 to 95 percent.

Frequency of individual symptoms.—The percent of persons in the Donora area of indicated age reporting individual symptoms is given in table 8. The single symptom most frequently reported was cough, a symptom reported for one-third of all persons in the Donora area. Of persons reporting cough, approximately two-thirds stated that the cough was nonproductive, while the remaining third reported a productive cough frequently productive of a black sputum. Both sore throat and constriction of chest were reported by more than 20 percent of all persons in the area, while dyspnoea with or without orthopnoea was also experienced by more than 20 percent.

Age variation in the frequency of reported symptoms is shown graphically in figure 7. It will be observed that the symptoms have been grouped according to type. For purposes of graphical presentation, nonproductive cough is shown with upper respiratory symptoms, and productive cough and constriction of chest are shown with lower respiratory symptoms.

The vertical scale of figure 7 is logarithmic, thus permitting a comparison of rates of change with age in the series of percentages for the various symptoms. Percentages for headache, and nausea without vomiting, among children less than 6 years of age are not given since these symptoms seem obviously under-reported for persons of these ages.

An examination of figure 7 reveals that percentages for each symptom tend to increase with age, particularly at ages under 55 years. The most marked increase with increasing age is shown for the various lower respiratory symptoms. For each of the symptoms in this section of the figure, the relative frequency with which the symptom was reported among persons 65 years of age and over is some 10 times the frequency with which it occurred among children less than 6 years of age.

It will be observed in table 8 that nonproductive and productive coughs considered as a single symptom remain the most frequently reported symptom in each age group. For each group under 45 years of age, sore throat was reported more frequently than constriction of chest; this relationship was reversed for ages 55 and over, the percentages being the same for persons 45–54 years of age.

Symptom frequencies are not shown separately by sex since no important sex differences appeared.

First symptoms.—Additional information on symptoms experienced by a selected group of affected persons is available from data recorded in interviews conducted by the physicians. These data were obtained for some 500 persons who were relatively severely affected by the smog.

Table 9, derived from these data, presents for affected persons with onset before and after 6 p. m. on day No. 2, the percent of persons reporting certain specified symptoms as first symptoms. An affected person may be included in more than one group if, for example, he reported eye irritation and sore throat as appearing first.

For affections beginning in each time period, the proportion of affected persons reporting eye irritation or cough as a first symptom decreased with increasing age, while the proportion of affected persons reporting dyspnoea or orthopnoea as a first symptom revealed an increase with age. Over two-thirds of affected persons 55 years of age and over reported dyspnoea as a first symptom in each time period. No consistent differences were observed between those who became ill before 6 p. m. of day No. 2 and those who became ill after that time.

Duration of symptoms.—Data on duration of symptoms among affected persons are available from interviews conducted by the physicians and referred to above. The median duration in days for various symptoms is given in table 10 for persons of all ages and those in each of four broad age groups.

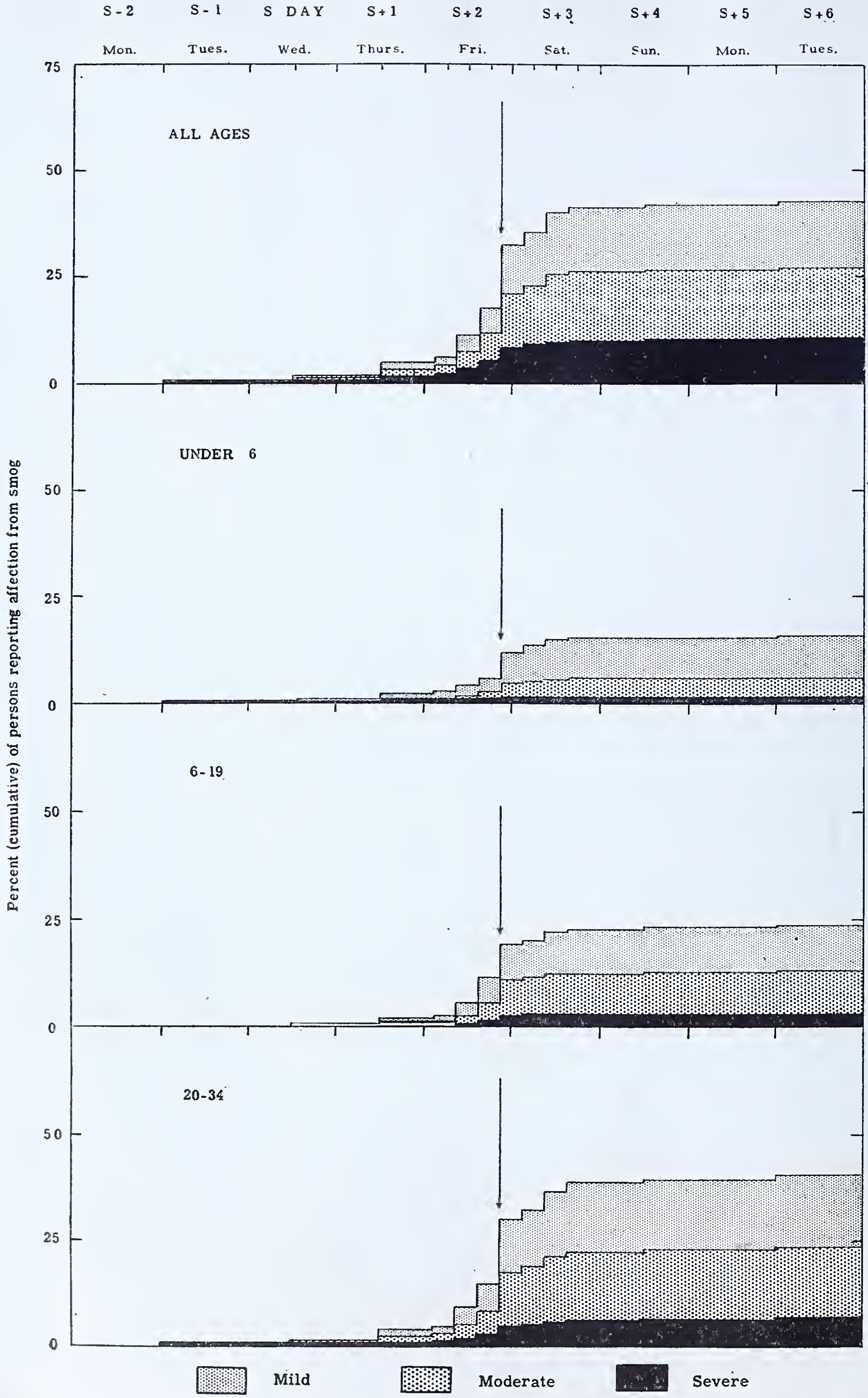


FIGURE 6.—*Incidence of smog affection among persons of indicated age in Donora area during a cumulative period beginning two days before S-day. (Figure continued on opposite page.)*

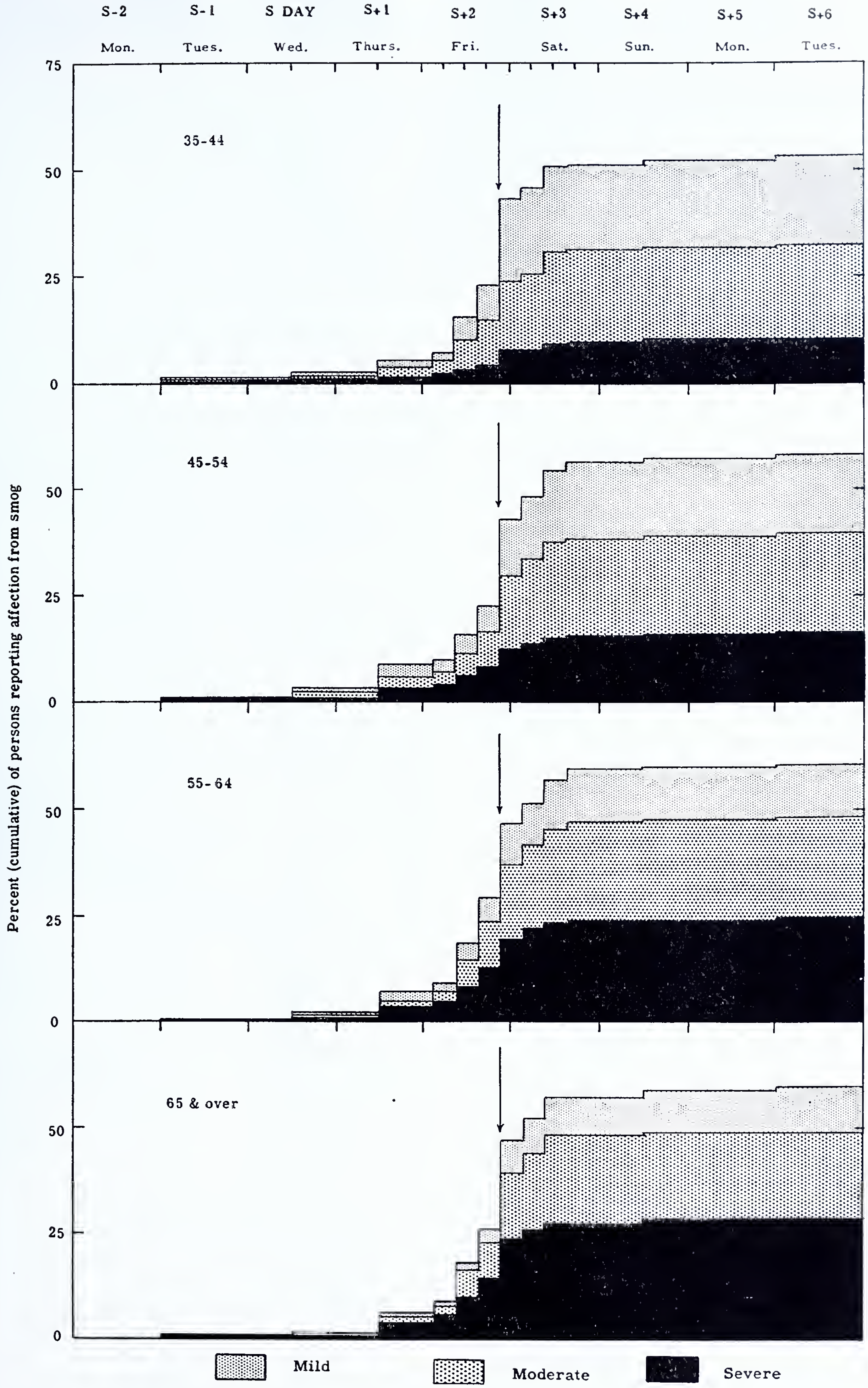


FIGURE 6—Continued.

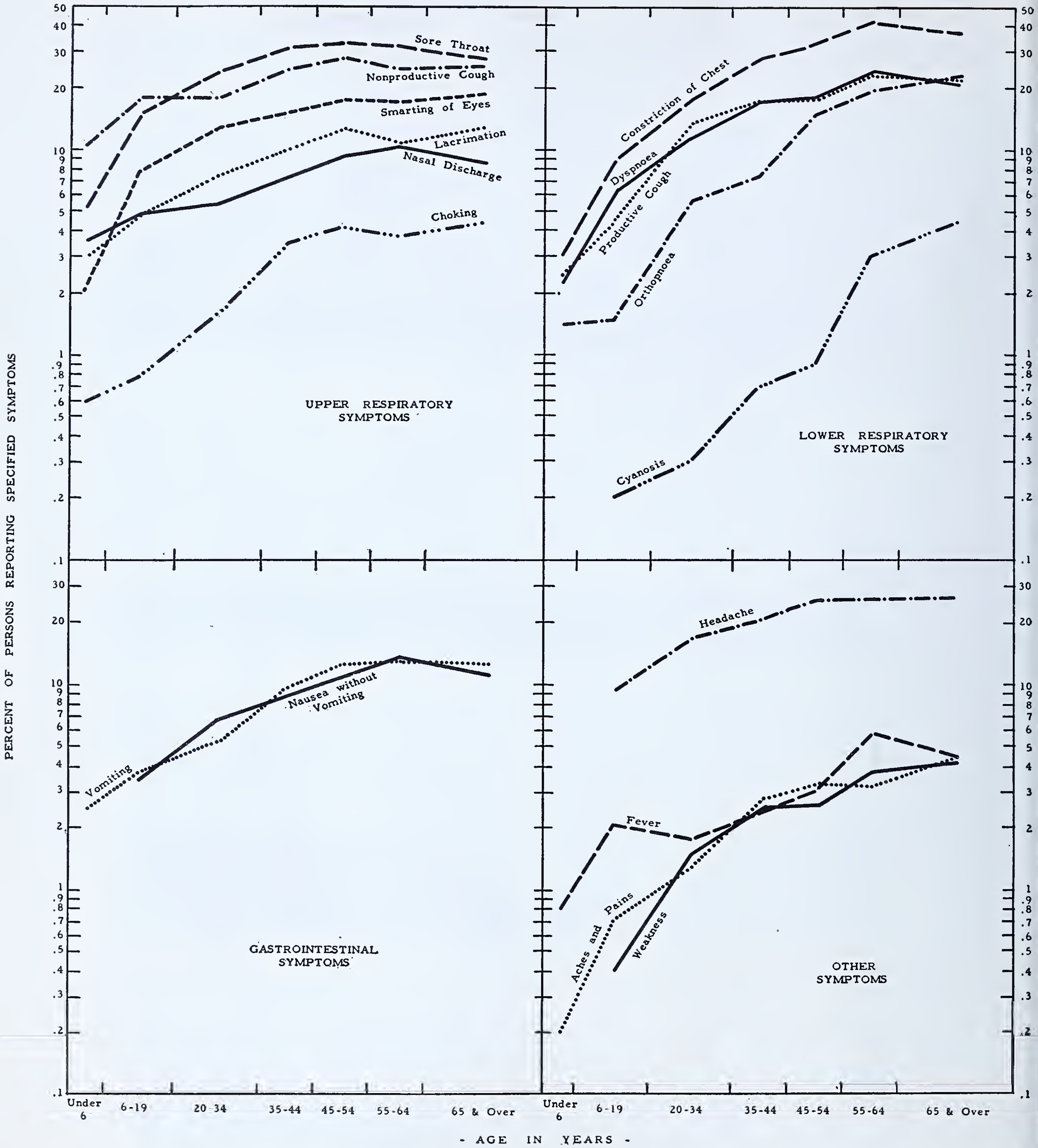


FIGURE 7.—*Frequency of specified symptoms among persons of indicated age in Donora area. (Logarithmic vertical scale.)*

For all ages, weakness and epigastric distress yield the longest median durations with a record of seven and five days, respectively. Cough and chest pain yield median durations of four to five days, while dyspnoea, orthopnoea, and other lower respiratory symptoms yield median durations of two to three days.

With the exception of epigastric distress, table 10 reveals no striking increase in median duration with age. It appears, therefore, that while the proportion of severely affected persons increased markedly with age, within the group of persons so affected duration of symptoms does not reveal any consistent variation with age.

TABLE 9.—*Percent of a selected group of affected persons of indicated age in Donora area, reporting the specified symptoms as first symptoms, according to time of onset of affection*

Symptom	Time of onset: Before 6 p. m. of day No. 2				After 6 p. m. of day No. 2			
	All ages	Age in years			All ages	Age in years		
		Under 35	35–54	55 and over		Under 35	35–54	55 and over
Eye irritation or nasal discharge	18	24	18	14	19	28	14	18
Throat irritation	35	43	34	32	41	44	49	27
Cough	44	57	43	39	50	58	48	47
Dyspnoea	58	33	60	68	55	30	56	73
Orthopnoea	30	18	33	34	26	5	27	42
Chest pain	36	26	42	36	41	33	39	48
Epigastric distress, nausea and vomiting	19	29	28	17	21	16	24	20

TABLE 10.—*Median duration in days of symptoms reported by a selected group of affected persons of indicated age in Donora area*

Symptom	Median duration of symptom in days: All ages	Age in years: Under 20	20–34	35–54	55 and over
Upper respiratory symptoms:					
Eye irritation	2. 8	2. 6	3. 5	2. 0	3. 3
Nasal discharge	3. 0	3. 8	3. 7	2. 5	3. 7
Sore throat	3. 9	3. 8	3. 4	3. 9	4. 3
Dry throat	4. 0	2. 0	4. 0	4. 0	5. 0
Upper or lower respiratory symptoms:					
Nonproductive cough	4. 2	4. 3	5. 2	3. 2	4. 4
Productive cough	4. 8	5. 0	4. 2	4. 9	5. 0
Chest pain	4. 4	2. 6	4. 4	4. 7	4. 4
Lower respiratory symptoms:					
Dyspnoea	2. 9	2. 3	2. 4	2. 5	3. 5
Orthopnoea	2. 6	2. 2	4. 3	2. 2	3. 2
Wheezing	2. 9	2. 2	2. 0	2. 7	3. 3
Palpitation	2. 8	3. 0	3. 0	2. 3	3. 3
Cyanosis	2. 6	1. 0	4. 0	2. 3	2. 8
Gastrointestinal symptoms:					
Epigastric distress	5. 0	1. 0	3. 0	6. 3	20. 4
Nausea	2. 0	1. 6	2. 0	2. 1	2. 1
Vomiting	1. 4	1. 6	. 8	1. 7	. 9
Anorexia	4. 4	4. 5	3. 2	4. 0	4. 8
Abdominal pain	2. 8	4. 3	2. 3	2. 2	4. 0
Other symptoms:					
Headache	3. 2	2. 4	3. 3	2. 9	3. 7
Fever	1. 9	1. 9	. 9	1. 8	2. 4
Chills	2. 0	. 9	1. 9	1. 6	2. 4
Weakness	7. 1	5. 0	5. 0	6. 7	8. 6

Symptoms present at time of survey.—The frequency with which symptoms from the smog persisted as long as four months after the smog period, that is, at the time of the household survey, is shown in table 11. It will be observed that over five percent of the total population reported the presence of cough at the time of the survey. Over two percent reported the persistence of constriction of the chest and dyspnoea, and over one percent reported the continued presence of a sore throat. Except for sore throat, this persistence of symptoms tended to increase markedly with age.

TABLE 11.—*Percent of persons of indicated age in Donora area, reporting presence of symptoms 4 months after smog period*

Symptom	All ages	Age in years: Under 20	20–34	35–54	55 and over
Sore throat	1. 4	0. 3	1. 7	2. 2	1. 9
Cough	5. 4	. 9	3. 8	8. 0	12. 0
Constriction of chest	2. 1	. 1	1. 0	3. 3	5. 1
Dyspnoea	2. 6	. 2	. 8	3. 9	7. 7

Duration of disability.—Severity of affection for persons in the household survey was determined by a combination of factors including duration of disability, that is, the time period during which the person was unable to carry on his accustomed duties. Table 12 presents for all ages and each of four broad age groups the percent of persons in the Donora area reporting affection from smog causing disability of 1–7 days, 8–14 days, and 15 days or longer. For all ages, and each of the broad age groups, over 80 percent of disabling affections lasted one week or less; the percent of persons disabled for more than two weeks was 0.4 for persons less than 20 years of age, 0.7 for persons 35–54 years of age, and 1.2 for persons 55 years of age and over. No disabilities of more than two weeks were reported for persons 20–34 years of age. For the population as a whole, these disability rates would yield 8,457 days lost because of illness due to the smog.

Incidence of smog affection among persons with bronchial asthma, heart disease, or chronic bronchitis.—Since the symptoms of smog affection, particularly in severe cases, were of a type frequently associated with cardiorespiratory disturbances, it is of interest to examine the incidence of smog affection among persons with diagnosed conditions of bronchial asthma, heart disease, or chronic bronchitis. About 340 or 2.4 percent of all persons in the Donora area had a history of bronchial asthma, 435 or 3.1 percent had a history of heart disease, and about 215 or 1.5 percent had a history of chronic bronchitis. Comparable percentages

TABLE 12.—*Percent of persons of indicated sex and age, in Donora area, reporting affection from smog causing disability of specified duration*

Age in years	Percent of persons reporting affection from smog					
	Total of all affection	Non-disabling affection	Disabling affection			
			Total	Duration in calendar days		
				1–7	8–14	15 or more
	Both sexes					
All ages	42. 7	32. 2	10. 5	8. 8	1. 2	0. 5
Under 20	24. 2	20. 0	4. 2	3. 5	. 3	. 4
20–34	40. 3	34. 7	5. 6	5. 3	. 3	0
35–54	55. 7	43. 8	11. 9	9. 9	1. 3	. 7
55 and over	60. 2	33. 8	26. 4	21. 5	3. 7	1. 2
	Males					
All ages	43. 0	32. 3	10. 7	9. 2	1. 0	0. 5
Under 20	23. 4	19. 1	4. 3	3. 6	. 3	. 4
20–34	40. 5	34. 4	6. 1	6. 1	0	0
35–54	56. 9	44. 7	12. 2	10. 6	. 9	. 7
55 and over	61. 3	36. 5	24. 8	20. 1	3. 4	1. 3
	Females					
All ages	42. 4	32. 1	10. 3	8. 5	1. 3	0. 5
Under 20	25. 1	21. 1	4. 0	3. 4	. 3	. 3
20–34	40. 1	35. 0	5. 1	4. 6	. 5	0
35–54	54. 6	42. 9	11. 7	9. 2	1. 8	. 7
55 and over	58. 9	30. 4	28. 5	23. 4	4. 0	1. 1

from the National Health Survey,[7] made in 1935–36, are 0.9 for bronchial asthma, 1.9 for heart disease, and 1.2 for chronic bronchitis. Bronchial asthma and heart disease appear, therefore, to be somewhat more prevalent among persons in the Donora area than in the United States as a whole. The meaning of these differences, although possibly of regional origin, is not fully apparent at this time.

Table 13 gives the prevalence of bronchial asthma, heart disease, and chronic bronchitis among males and females of the Donora area in four broad age groups. It will be observed that, for the three conditions, the prevalence of chronic bronchitis, although it is shown to increase notably less with increasing age than heart disease or bronchial asthma, still shows a marked increase. About 8 percent of males 55 years of age and over reported a history of bronchial asthma or heart disease; only 5 percent of females in this age group reported bronchial asthma, while not quite 10 percent reported heart disease. For each age group 20 years and over,

[7] The National Health Survey was a house-to-house survey of an urban population with 48 percent males and 52 percent females. Ten percent of the population were Negro, and the age distribution of persons in the survey was the same as the age distribution of the population of the United States. Data from the survey were kindly supplied by Dr. S. D. Collins, Public Health Service.

TABLE 13.—*Prevalence of bronchial asthma, heart disease, and chronic bronchitis among persons of indicated sex and age in Donora area*

Age in years	Percent of persons of indicated sex and age reporting specified condition		
	Bronchial asthma	Heart disease	Chronic bronchitis
	Both sexes		
All ages	2. 4	3. 1	1. 5
Under 20	1. 7	. 6	1. 1
20–34	. 8	1. 7	1. 1
35–54	2. 0	4. 0	2. 1
55 and over	6. 8	8. 3	2. 1
	Males		
All ages	2. 9	2. 3	1. 2
Under 20	1. 7	. 4	. 5
20–34	. 5	1. 1	1. 3
35–54	2. 6	1. 9	1. 7
55 and over	7. 9	7. 5	1. 7
	Females		
All ages	2. 0	4. 0	1. 9
Under 20	1. 6	. 9	1. 8
20–34	. 9	2. 2	. 9
35–54	1. 4	6. 2	2. 5
55 and over	5. 4	9. 4	2. 7

diagnosed heart disease was more prevalent among females than among males. This relationship was also evidenced in data collected in the National Health Survey.

Table 14 shows the incidence of smog affection among persons in the Donora area of indicated age and with a health history of bronchial asthma, heart disease, or chronic bronchitis. Comparable rates for all persons in the Donora area are also given. Although the number of cases in each category is small, the observed differences were sufficiently striking to be presented since they appeared to be valid differences.

It will be observed in table 14 that the incidence of all smog affection was 87.6 percent among persons with asthma, 77.2 percent among persons with heart disease, and 78.9 percent among persons with chronic bronchitis. These rates are all well above the rate of 42.7 percent recorded for the total population of the area. Over one-half of persons with bronchial asthma were severely affected, more than one-third of persons with heart disease were severely affected, and over one-fourth of persons with chronic bronchitis were severely affected.

For each age group, the incidence of all affection from the smog was markedly higher among persons with each of the three conditions than among the corresponding group in the general population. Over three-fourths of persons 20 years of age and over, and with bronchial asthma, heart disease, or chronic bronchitis, reported some affection from the smog.

TABLE 14.—*Incidence of smog affection among persons in Donora area with a health history of bronchial asthma, heart disease, or chronic bronchitis, by age*

Population group	Percent of persons in indicated population group affected by smog			
	Total	Degree of affection		
		Mild	Moderate	Severe
	All ages			
Total, Donora area	42. 7	15. 5	16. 8	10. 4
Persons with bronchial asthma	87. 6	11. 5	19. 5	56. 6
Persons with heart disease	77. 2	11. 7	29. 0	36. 5
Persons with chronic bronchitis	78. 9	12. 7	39. 4	26. 8
	Under 20 years of age			
Total, Donora area	24. 2	13. 5	8. 3	2. 4
Persons with bronchial asthma	66. 7	20. 8	25. 0	20. 9
Persons with heart disease	55. 6	11. 1	33. 4	11. 1
Persons with chronic bronchitis	56. 2	12. 5	25. 0	18. 7
	20–34 years of age			
Total, Donora area	40. 3	16. 7	17. 2	6. 4
Persons with bronchial asthma	88. 9	11. 1	22. 2	55. 6
Persons with heart disease	80. 0	20. 0	30. 0	30. 0
Persons with chronic bronchitis	92. 3	23. 1	61. 5	7. 7
	35–54 years of age			
Total, Donora area	55. 7	19. 5	23. 1	13. 1
Persons with bronchial asthma	95. 7	17. 4	13. 1	65. 2
Persons with heart disease	78. 3	21. 8	26. 1	30. 4
Persons with chronic bronchitis	83. 3	16. 7	37. 5	29. 1
	55 years of age and over			
Total, Donora area	60. 2	11. 8	22. 2	26. 2
Persons with bronchial asthma	93. 0	5. 3	19. 3	68. 4
Persons with heart disease	78. 6	2. 9	30. 0	45. 7
Persons with chronic bronchitis	83. 3	0	38. 9	44. 4

The incidence of all smog affection among persons with each of the specified conditions remained relatively the same for persons 35–54 years of age and persons 55 years of age and over. For both age groups, the rate was over 90 percent for persons with asthma, and about 80 percent for persons with heart disease or chronic bronchitis. For persons with each of the given conditions, however, there was a marked shift with increasing age in the degree of severity of affection. For persons with asthma this shift occurred in the increased percentage of persons moderately, rather than mildly, affected; the percentage severely affected was unusually high for both age groups, representing almost two-thirds of all persons of those ages with asthma. For persons with heart disease or those with chronic bronchitis, the percentage severely affected increased with increasing age from about 30 to 45 percent. For both age groups, 35–54 years and 55 years of age and over, the incidence of moderate affection was higher among persons with chronic bronchitis than among persons with heart disease.

Residence Districts

The Donora area consists of the borough of Donora, located on the west bank of the Monongahela River; certain sections of Carroll Township adjacent to the borough; and the section of Rostraver Township across the river from Donora which includes the community of Webster. The Monongahela River divides the area into two distinct parts, namely, the section on the west bank of the river which will subsequently be referred to as Donora, and Carroll Township or simply as Donora, and the section on the east bank which will be referred to as Webster.

Each of these two regions was further arbitrarily subdivided into a number of residence districts. The districts were determined by the location of air-sampling stations within the area together with certain natural characteristics of the terrain. Twelve air-sampling stations had been set up in the area, 7 in Donora, and Carroll Township, and 5 in Webster, and correspondingly there were determined 12 districts, each district being given the number of the air-sampling station lying within it.

The various residence districts are shown on the map presented in figure 8. Another section of this report depicts the terrain of the area. As was observed in that description, the sides of the river valley were rather steep, rising rapidly from about 700 feet above sea level at the river to about 1,100 feet at the highest inhabited area. With this in mind, the factor of elevation was used in delineating the residence districts.

In the analysis, data will not be presented specifically for districts 5, 7, or 8, in Webster, since these were sparsely populated areas. The experience of persons in these districts, however, was included in total figures for Webster as a whole. About 250 persons living in Carroll Township were outside the limits of the given residence districts, but were included in total figures for Donora, and Carroll Township.

Population characteristics.—Of the total of 13,839 persons in the Donora area, 12,927 lived in Donora, and Carroll Township, and 912 lived in Webster. The population of the various residence districts in Donora ranged from almost 700 in district 12 to about 4,500 in district 10. Districts 4 and 6 in Webster included 387 and 357 persons, respectively.

Districts 9 and 10 were large residential districts where the majority of houses were one-family residences, owned by the family. District 1, lying partly in Carroll Township, included a number of new suburban developments, and was also principally a section of one-family homes. Districts 2 and 11. on the other hand, contained a fairly large number of houses which had been converted into two- or three-family dwellings. Districts 3 and 12 were business districts, and included a relatively large number of rooming houses and apartment buildings, the latter, in many instances, having commercial establishments on the first floor.

FIGURE 8.—*Map showing Donora area divided into residence districts, and location of corresponding air-sampling stations.*

No specific data on the composition of the various districts with regard to sex, race, or occupational status will be given at this time, since, as has already been shown, these factors appeared to have relatively little influence on the incidence of smog affection. It may be noted, however, that sex, race, and occupational distributions for the various districts were generally quite similar.

The age distribution of persons in the different residence districts is shown in table 15. An examination of table 15 reveals that for Webster the proportion of persons under 20 years of age was somewhat higher than the corresponding proportion for the area as a whole. Among districts in Donora, persons living in district 1 tended to be younger, on the average, than persons in the whole area, while a relatively older group lived in district 12. With these exceptions, the age distribution of persons in the various districts showed no marked variation. Observed differences, moreover, do not appear sufficiently great to invalidate interdistrict comparisons of incidence rates of smog affection for persons of all ages combined.

TABLE 15.—*Age distribution of persons in residence districts of Donora area*

Residence district	All ages	Age in years: Under 20	20–34	35–54	55 and over
	Percent				
Total, Donora area	100. 0	31. 3	25. 8	24. 7	18. 2
Donora, and Carroll Township [1]	100. 0	30. 9	25. 7	25. 1	18. 3
1	100. 0	34. 3	31. 4	21. 0	13. 3
2	100. 0	32. 8	25. 9	20. 9	20. 4
3	100. 0	32. 7	26. 3	25. 0	16. 0
9	100. 0	29. 3	20. 6	30. 3	19. 8
10	100. 0	31. 1	26. 1	24. 8	18. 0
11	100. 0	30. 0	29. 0	21. 4	19. 6
12	100. 0	23. 7	23. 7	28. 9	23. 7
Webster [2]	100. 0	35. 5	27. 6	19. 4	17. 5
4	100. 0	35. 7	31. 0	17. 8	15. 5
6	100. 0	38. 6	24. 4	20. 2	16. 8
	Number [3]				
Total, Donora area	13, 839	4, 326	3, 570	3, 423	2, 520
Donora, and Carroll Township [1]	12, 927	4, 002	3, 318	3, 246	2, 361
1	945	324	297	198	126
2	1, 482	486	384	309	303
3	1, 644	537	432	411	264
9	2, 346	687	483	711	465
10	4, 587	1, 425	1, 200	1, 137	825
11	981	294	285	210	192
12	696	165	165	201	165
Webster [2]	912	324	252	177	159
4	387	138	120	69	60
6	357	138	87	72	60

[1] Includes 246 persons in other sections of Carroll Township.
[2] Includes 168 persons in other sections of Webster.
[3] See footnote 1, table 2.

Webster.—Since the total population of Webster was less than 1,000 persons while that of Donora, and Carroll Township was almost 13,000, data discussed previously for the Donora area as a whole reflect principally the experience of persons in Donora, and Carroll Township. Because the death rate during the smog period was higher in Webster than in Donora, it is of interest to examine briefly, data on smog affection for Webster as a whole, before discussing the experience of persons living in the various residence districts.

The following table shows the incidence of smog affection in Webster, together with comparable rates for the Donora area:

Age in years	Total: Webster	Total: Donora area	Degree of affection: Mild: Webster	Mild: Donora area	Moderate: Webster	Moderate: Donora area	Severe: Webster	Severe: Donora area
All ages	55. 9	42. 7	19. 7	15. 5	22. 7	16. 8	13. 5	10. 4
Under 20	31. 5	24. 2	17. 6	13. 5	12. 0	8. 2	1. 9	2. 5
20–34	53. 6	40. 2	19. 1	16. 7	27. 4	17. 1	7. 1	6. 4
35–54	77. 9	55. 7	27. 1	19. 5	28. 8	23. 1	22. 0	13. 1
55 and over	84. 9	60. 3	17. 0	11. 8	30. 2	22. 3	37. 7	26. 2

It will be observed in the table that for persons of all ages and for those in each of the four broad age groups, the incidence of all smog affection was higher for the Webster group than for the area as a whole. Fifty-six percent of all persons in Webster reported some affection from the smog, the age-specific rates increasing from 32 for persons under 20 years of age to 85 percent for persons 55 years of age and over.

With the exception of severe affection among persons under 20, the Webster rate for each degree of affection and age group exceeded the corresponding area rate. It will be observed in figure 9 that in general the age pattern of the rates yielded for the Donora area as a whole is retained, but at a higher level, in the rates recorded for Webster.

Incidence rates by residence district.—The percent of persons in each of the residence districts reporting affection from smog is given in table 16 for persons of all ages combined, and for those in four broad age groups. For districts in Donora, the incidence of smog affection ranged from 31.4 for district 2 to 51.7 for district 1. District 4 in Webster reported the highest incidence with 61.2 percent of its residents affected by smog, while district 6 experienced a rate of 52.1.

With the exception of district 4, the percent of persons in each residence district severely affected by the smog, was approximately 10 percent, the same rate yielded for the area as a whole. This rate was 18 for district 4. Again, with the exception of district 4, the percent of persons in each age group reporting severe affection showed relatively little variation among the residence districts. For district 4, the percent of persons severely affected increased from 2 percent of persons under 20 years of age (a rate of the same order of magnitude as the corresponding area rate for persons under 20) to 50 percent of all persons 55 years of age and over, a

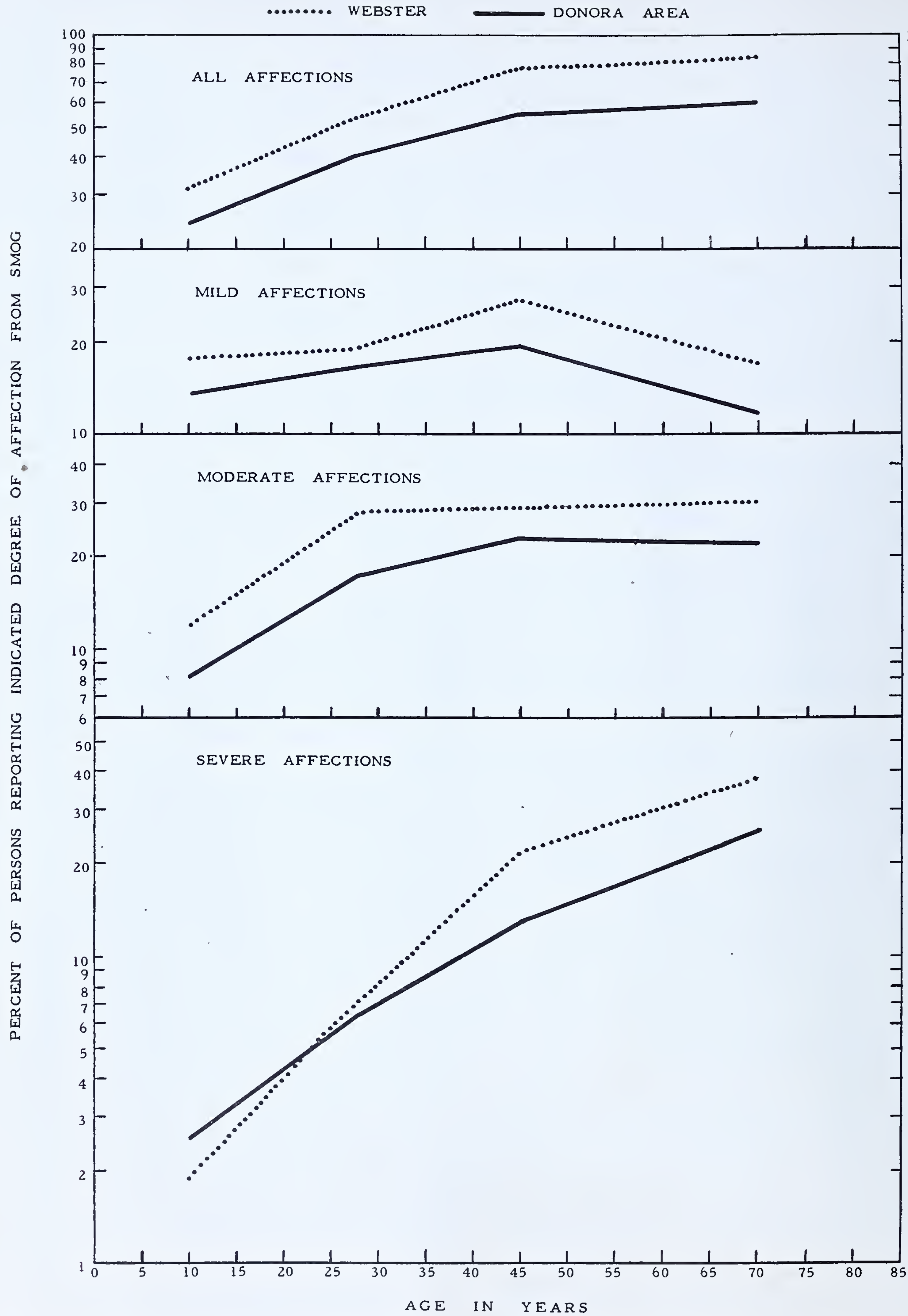


FIGURE 9.—*Age variation in incidence of smog affection among persons in Webster compared with that for the Donora area as a whole. (Logarithmic vertical scale.)*

Table 16.—*Incidence of smog affection among persons of indicated age in residence districts of Donora area*

Residence district	Percent of persons of indicated age in given residence district reporting affection from smog																			
	All ages				Age in years															
					Under 20				20–34				35–54				55 and over			
	Total	Degree of affection			Total	Degree of affection			Total	Degree of affection			Total	Degree of affection			Total	Degree of affection		
		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe		Mild	Moderate	Severe
Total, Donora area	42. 7	15. 5	16. 8	10. 4	24. 2	13. 5	8. 2	2. 5	40. 2	16. 7	17. 1	6. 4	55. 7	19. 5	23. 1	13. 1	60. 3	11. 8	22. 3	26. 2
Donora, and Carroll Township [1]	41. 8	15. 2	16. 4	10. 2	23. 6	13. 2	7. 9	2. 5	39. 2	16. 5	16. 4	6. 3	54. 5	19. 1	22. 8	12. 6	58. 6	11. 5	21. 7	25. 4
1	51. 7	20. 9	20. 9	9. 9	35. 2	25. 0	7. 4	2. 8	54. 6	21. 2	26. 3	7. 1	68. 2	21. 2	33. 3	13. 7	61. 9	9. 5	23. 8	28. 6
2	31. 4	11. 8	10. 1	9. 5	15. 4	7. 4	4. 9	3. 1	26. 6	12. 5	8. 6	5. 5	39. 8	12. 6	13. 6	13. 6	54. 4	16. 8	16. 8	20. 8
3	37. 2	11. 5	15. 9	9. 8	21. 2	5. 0	12. 3	3. 9	37. 5	14. 6	18. 0	4. 9	48. 9	17. 5	19. 7	11. 7	51. 1	10. 2	13. 6	27. 3
9	40. 9	13. 8	16. 5	10. 6	20. 1	9. 2	8. 3	2. 6	31. 1	13. 7	11. 2	6. 2	57. 4	20. 3	24. 0	13. 1	56. 8	11. 0	22. 6	23. 2
10	44. 3	15. 9	17. 7	10. 7	24. 0	13. 9	8. 0	2. 1	45. 0	17. 3	19. 5	8. 2	55. 4	20. 3	22. 2	12. 9	63. 3	11. 3	25. 8	26. 2
11	46. 5	20. 8	15. 9	9. 8	35. 7	26. 5	7. 2	2. 0	36. 8	21. 0	10. 5	5. 3	60. 0	20. 0	27. 1	12. 9	62. 5	12. 5	25. 0	25. 0
12	44. 0	15. 5	17. 7	10. 8	30. 9	25. 4	5. 5	0	36. 4	16. 4	18. 2	1. 8	55. 2	16. 4	26. 9	11. 9	50. 9	3. 6	18. 2	29. 1
Webster [2]	55. 9	19. 7	22. 7	13. 5	31. 5	17. 6	12. 0	1. 9	53. 6	19. 1	27. 4	7. 1	77. 9	27. 1	28. 8	22. 0	84. 9	17. 0	30. 2	37. 7
4	61. 2	16. 3	27. 1	17. 8	39. 1	21. 7	15. 2	2. 2	55. 0	10. 0	32. 5	12. 5	87. 0	21. 7	34. 8	30. 5	95. 0	10. 0	35. 0	50. 0
6	52. 1	26. 9	16. 8	8. 4	28. 3	19. 6	6. 5	2. 2	55. 2	31. 0	20. 7	3. 5	70. 8	37. 5	20. 8	12. 5	80. 0	25. 0	30. 0	25. 0

[1] Includes the experience of 246 persons in other sections of Carroll Township.

[2] Includes the experience of 168 persons in other sections of Webster.

rate almost twice the corresponding rate recorded for persons of these ages in the Donora area.

Onset of affection.—Figure 10 presents graphically the cumulative percentages of persons in the various districts reporting affection from the smog beginning in a period extending from 2 days before S-day to an indicated later time. Thus, the first section of the figure shows the percent of persons in each district affected in the period from two days before S-day to 6 a. m. of day No. 2. The section immediately below gives the percent affected in the period beginning at the same time (2 days before S-day) but extending to 6 p. m. of day No. 2. The final section of the figure represents the percent affected in the period from 2 days before S-day to midnight of day No. 6, that is, throughout the whole period considered.

For purposes of graphical presentation, the residence districts have been ordered as follows: 1, 10, 9, 2, 11, 12, 3, 4, 6. If figure 8 is examined in connection with this ordering, it will be observed that the first 7 districts are in Donora, and are given essentially in order of decreasing elevation, ending with district 3. District 4 is the district in Webster directly across the river from district 3 and with the same elevation. District 6 lies somewhat beyond district 4, and increases in elevation.

An examination of figure 10 reveals the following relationships, among others:

(1) Up to 6 p. m. of day No. 2, the highest percent of persons affected was in district 12. It will be recalled in this connection, however, that persons in district 12 were older, on the average, than persons in the area as a whole.

(2) Although for the over-all period, the highest incidence of smog affection in districts of Donora occurred in district 1, the rate for this district did not exceed corresponding rates for other districts in Donora until midnight of day No. 2.

(3) By midnight of day No. 2, the relative magnitude of incidence rates for the various residence districts of Donora was fairly well determined. This was not so in Webster. Up until midnight of day No. 2, rates for district 4 were of an order of magnitude similar to that of rates for the Donora districts. By noon of day No. 3, however, the incidence of smog affection in district 4 exceeded the incidence in all other districts, and this excess was increased by the end of the period.

Frequency of symptom complexes.—Table 17 presents the percent of persons in each of the residence districts reporting

Table 17.—*Frequency of symptom complexes among persons in residence districts of Donora area*

Residence district	Percent of persons in given residence district reporting one or more symptoms of specified complex				
	All symptoms	Upper respiratory symptoms	Lower respiratory symptoms	Gastrointestinal symptoms	Other symptoms
Total, Donora area	42. 7	39. 2	37. 2	14. 5	19. 4
Donora, and Carroll Township [1]	41. 8	38. 2	36. 2	14. 1	19. 1
1	51. 7	49. 8	46. 0	19. 7	20. 3
2	31. 4	28. 9	26. 1	9. 3	12. 6
3	37. 2	34. 9	33. 4	14. 6	18. 1
9	40. 9	38. 1	35. 2	13. 9	20. 2
10	44. 3	39. 5	38. 1	15. 4	21. 6
11	46. 5	41. 6	41. 0	10. 7	18. 0
12	44. 0	39. 7	38. 4	14. 2	18. 1
Webster [2]	55. 9	53. 0	51. 3	20. 4	23. 0
4	61. 2	59. 1	60. 6	23. 5	27. 3
6	52. 1	48. 7	47. 1	21. 0	21. 8

[1] Includes the experience of 246 persons in other sections of Carroll Township.
[2] Includes the experience of 168 persons in other sections of Webster.

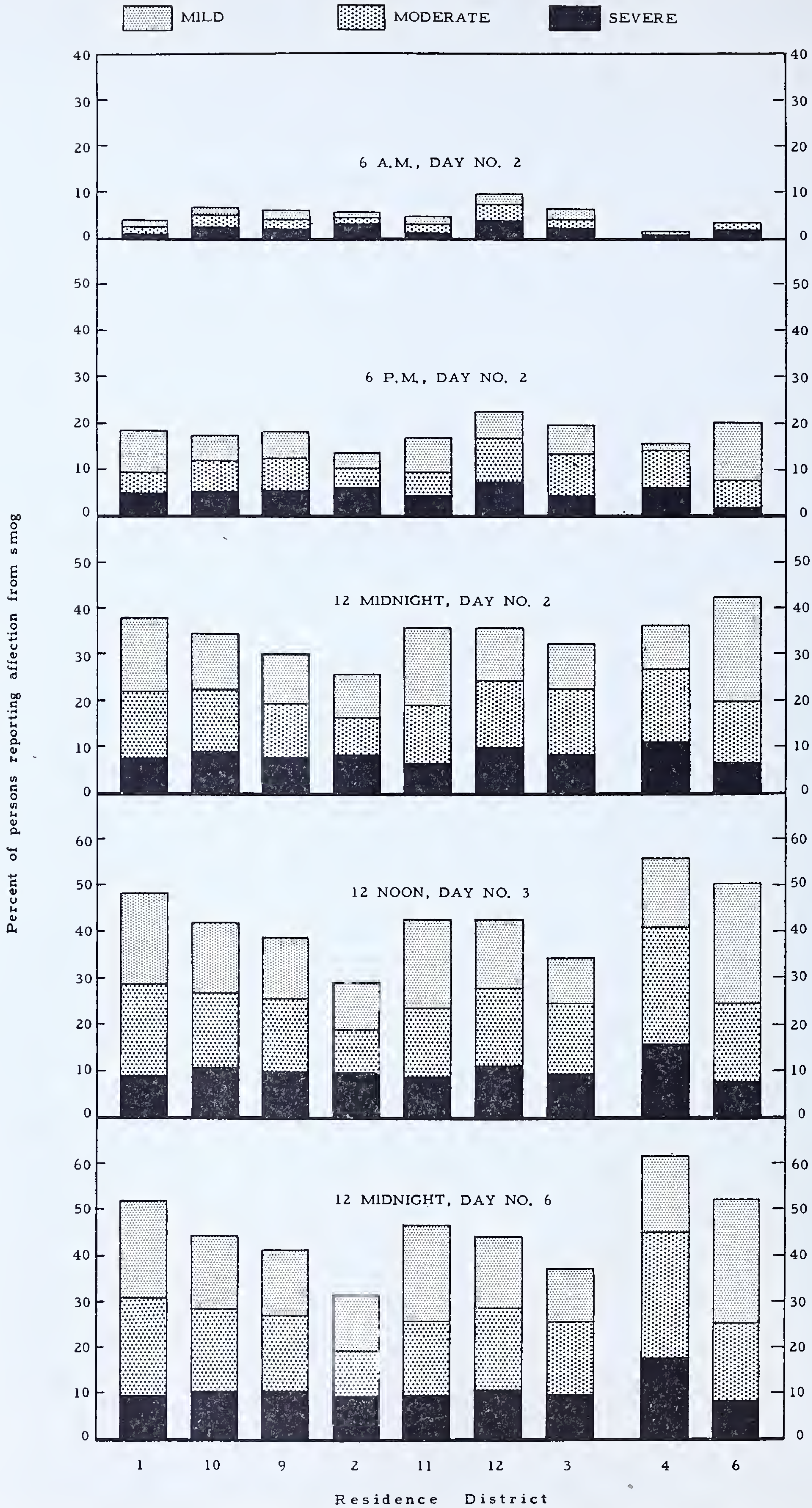


FIGURE 10.—*Incidence of smog affection among persons in residence districts of Donora area during a cumulative period beginning two days before S-day, and ending at indicated time.*

one or more symptoms of the four given complexes, namely, upper respiratory, lower respiratory, gastrointestinal, and "other."

In general, variation among districts in the frequency of upper and lower respiratory symptoms follows the inter-district pattern of variation in incidence of smog affection. Thus, the highest frequency for each of the two complexes occurred in district 4, while district 1 ranked highest among districts in Donora. For each district except district 4, upper respiratory symptoms exceeded lower respiratory symptoms in frequency. Over 80 percent of affected persons in each district, however, reported the presence of upper or lower respiratory symptoms.

The frequency of gastrointestinal symptoms was relatively low in both districts 2 and 11, while the frequency of "other" symptoms was low in district 2. Gastrointestinal symptoms appeared relatively frequently in districts 1, 4, and 6, while the frequency of "other" symptoms was high in district 4.

Frequency of individual symptoms.—The frequency of individual symptoms in the various residence districts is given in table 18. Symptoms reported by more than 5 percent of all persons in the area are presented graphically in figure 11; the districts are again ordered as in figure 10.

It will be observed in figure 11 that smarting of eyes and lacrimation were reported relatively frequently in districts 12, 3, and 4, and relatively infrequently in districts 2 and 11. Sore throat, nonproductive cough, constriction of chest, and headache were notably less in district 2 than in the other districts. The frequency of productive cough was notably high in district 4, while sore throat appeared relatively frequently in both districts 1 and 4. For 8 of the 12 symptoms shown in figure 11, the highest frequency was recorded for district 4. For all symptoms except smarting of eyes and dyspnoea without orthopnoea, the lowest frequency was recorded for district 2.

Summary of Findings

1. A total of 5,910 persons or 42.7 percent of the total population of the Donora area reported some affection from the smog of October 1948.

2. Of these, 2,148 persons were midly affected, 2,322 were moderately affected, and 1,440 were severely affected, these numbers representing, respectively, 15.5, 16.8, and 10.4 percent of the population.

3. Incidence of smog affection was relatively little influenced by sex, race, or occupational status.

4. Incidence rates show marked variation with age. For all degrees of affection, the percent of persons affected increased from 16 percent of children under 6 years of age to 60 percent, or almost two-thirds, of all persons 65 years of age and over. Of all adults in the Donora area one-half experienced some affection from the smog.

5. There was a marked change with age in the composition of the affected group in respect of severity of affection. Only about one-tenth of affected persons less than 6 years of age were severely affected, but almost one-half of affected persons 65 years of age and over were in the severely affected group. The corresponding incidence rates range from two to almost 30 percent of the respective population groups representing both the affected and nonaffected persons.

TABLE 18.—*Frequency of individual symptoms among persons in residence districts of Donora area*

Symptom	Percent of persons in given residence district reporting specified symptom											
	Total, Donora area	Donora, and Carroll Township								Webster		
		Total [1]	Residence district							Total [2]	Residence district	
			1	2	3	9	10	11	12		4	6
Upper respiratory symptoms:												
Smarting of eyes	12.3	12.0	14.9	8.9	15.0	11.4	11.7	8.3	16.4	15.5	20.9	10.9
Lacrimation	8.0	7.8	9.2	3.4	11.3	7.5	8.2	4.3	9.9	10.2	12.4	8.4
Nasal discharge	6.6	6.8	6.7	3.8	9.3	7.8	7.1	4.6	6.5	3.3	5.4	0
Choking	2.3	2.1	1.9	4.3	2.0	1.8	1.6	2.4	2.6	5.9	2.3	6.7
Sore throat	23.1	22.6	31.1	12.8	22.8	23.3	23.0	24.5	23.7	30.6	34.1	26.9
Upper or lower respiratory symptoms:												
Cough	33.1	32.0	42.9	21.0	30.9	30.7	33.3	36.1	34.5	47.7	55.8	43.7
Nonproductive	20.2	19.8	27.3	11.7	17.9	19.1	20.3	26.0	23.3	25.7	25.6	31.1
Productive	12.9	12.2	15.6	9.3	13.0	11.6	13.0	10.1	11.2	22.0	30.2	12.6
Constriction of chest	21.5	20.9	25.4	16.2	19.9	21.7	21.1	23.5	20.3	29.9	31.8	28.6
Lower respiratory symptoms:												
Dyspnoea without orthopnoea	12.9	12.3	17.5	12.8	7.8	11.3	11.9	20.5	10.8	21.4	21.7	21.8
Orthopnoea	8.4	8.3	8.3	4.3	8.8	9.5	9.1	5.2	12.1	9.9	14.7	4.2
Cyanosis	1.0	1.0	.6	.6	.9	.4	1.5	1.2	.9	.7	.8	.8
Gastrointestinal symptoms:												
Nausea without vomiting	7.1	7.0	9.5	4.0	8.2	5.4	8.0	5.5	8.2	9.2	8.5	10.9
Vomiting	7.4	7.1	10.2	5.3	6.4	8.6	7.5	5.2	6.0	11.2	14.0	10.1
Diarrhea	.1	.1	.3	0	0	.1	0	0	0	.3	0	.8
Other symptoms:												
Headache	17.0	16.8	17.8	9.7	16.8	17.8	19.3	14.4	16.8	20.1	21.7	18.5
Fever	2.6	2.7	4.1	1.0	2.9	2.3	3.3	2.4	1.7	1.0	2.3	0
Weakness	1.8	1.8	2.2	2.0	.9	1.4	2.0	3.1	1.7	2.3	1.6	3.4
Aches and pains	1.9	1.8	1.6	1.2	1.1	2.7	1.9	1.8	1.7	3.9	4.7	3.4

[1] Includes the experience of 246 persons in other sections of Carroll Township.
[2] Includes the experience of 168 persons in other sections of Webster.

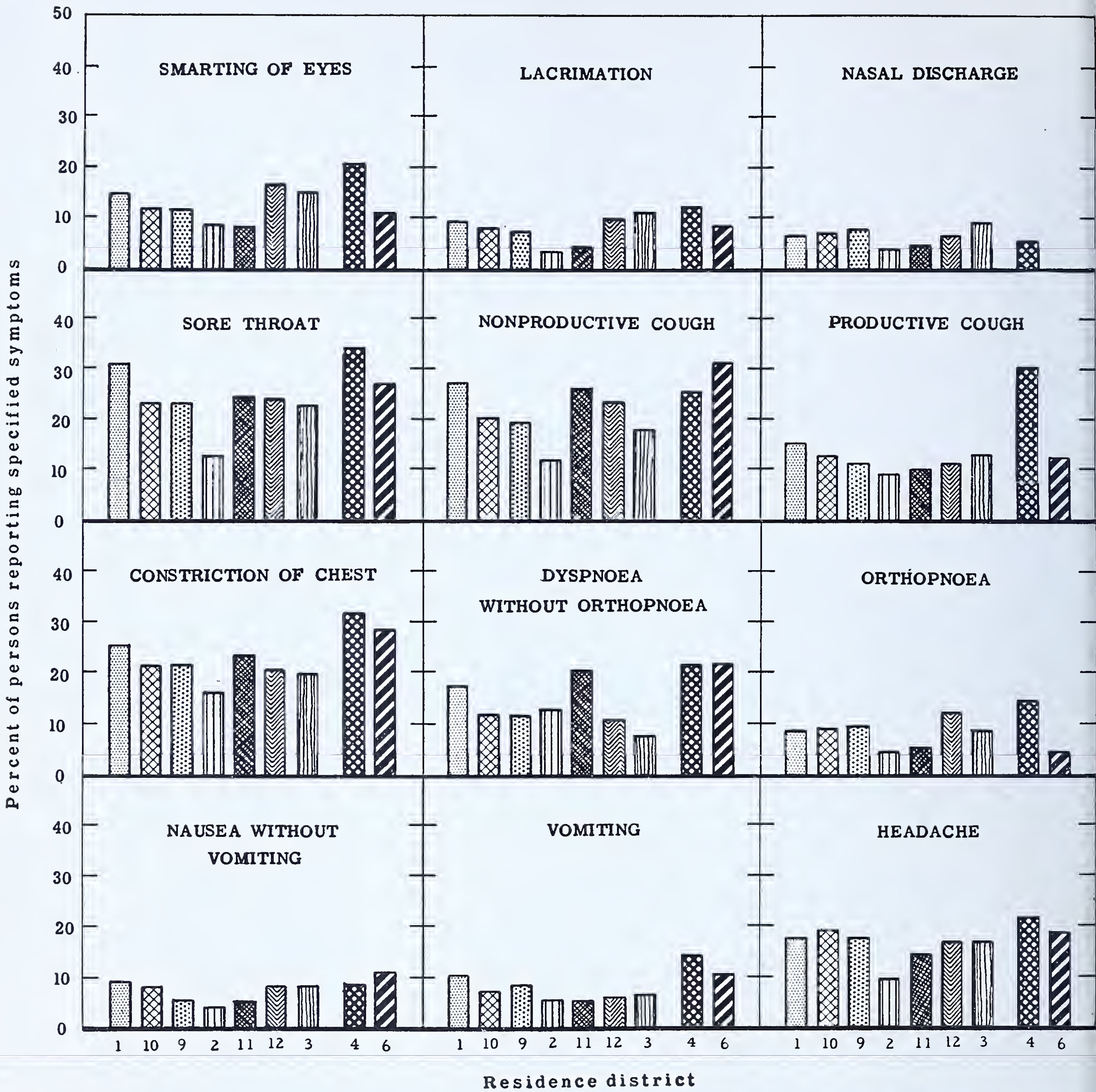


FIGURE 11.—*Frequency of specified symptoms among persons in residence districts of Donora area.*

6. About 40 percent of the affected persons reported onset of affection before 6 p. m. on day No. 2, 35 percent became ill during the 6 hours from 6 p. m. till midnight of that day, and the remaining 25 percent reported onset of affection after midnight of day No. 2. By midnight of day No. 2, one out of every three persons in the Donora area had experienced some affection from the smog.

7. The greatest relative increase during the period from 6 p. m. to midnight of day No. 2 occurred in the percent of persons becoming mildly affected; the smallest relative increase occurred in the percent of persons becoming severely affected.

8. Approximately one-half of all severe affections began before 6 p. m. on day No. 2, while less than 40 percent of the mild affections began before that time.

9. Over 90 percent of the affected group reported one or more upper respiratory symptoms, 87 percent reported lower respiratory symptoms, 34 percent reported gastrointestinal symptoms, and 45 percent reported "other" symptoms such as headache, weakness, and aches and pains.

10. The single symptom most frequently reported was cough, a symptom experienced by one-third of all persons in the area. Both sore throat and constriction of chest were reported by more than 20 percent of exposed persons, and

dyspnoea with or without orthopnoea was reported by over 20 percent.

11. The percent of persons reporting each symptom tended to increase with age, particularly at ages under 55 years. The most marked increase with increasing age was shown for the various lower respiratory symptoms.

12. For a selected group of severely affected persons, the median duration of the various symptoms showed relatively little change with age.

13. The incidence of smog affection was relatively high among persons with past histories of bronchial asthma, heart disease, or chronic bronchitis.

14. Among persons of all ages combined, and those in each of four broad age groups, the incidence of smog affection was higher in Webster than in the area as a whole. Fifty-six percent of all persons in Webster reported some affection from the smog, the age-specific rates increasing from 32 percent for persons under 20 years of age to 85 percent for persons 55 years of age and over.

15. In general, the age pattern of rates for the different degrees of affection exhibited by the Donora area as a whole was retained, but at a higher level in rates recorded for Webster.

16. Among different residence districts in Donora, the incidence of smog affection ranged from 31.4 percent for district 2, to 51.7 percent for district 1. District 4 in Webster reported the highest incidence with 61.2 percent of its residents affected by smog, while district 6, also in Webster, experienced a rate of 52.1.

17. Except for district 4, the percent of persons in each district severely affected by the smog was approximately 10 percent, the same rate yielded for the area as a whole. For district 4, this rate was 18, a rate which is significantly higher than the corresponding area rate.

18. Up until midnight of day No. 2, rates for district 4 were less than, or similar in magnitude to, rates for the various districts in Donora. By noon of day No. 3, however, the incidence of smog affection in district 4 exceeded the incidence in all other districts, and this excess was increased by the end of the period considered.

19. Over 80 percent of affected persons in each of the residence districts reported the presence of upper or lower respiratory symptoms.

20. For 8 of 12 specific symptoms reported by more than 5 percent of the total population of the Donora area, the highest frequency was recorded for persons living in district 4. For all but two symptoms, the lowest frequency was recorded for district 2.

HOSPITALIZED PERSONS

About 50 persons were hospitalized during the smog period; the records of 32 were obtained to study certain phases of the acute smog illness not available to us from other sources. The hospital records were in various stages of completeness from the point of view of studies made of the patients. The cases are presented in detail at the end of this section. The group consisted of 25 males and 7 females with ages ranging from 8 to 76 years. More than two-thirds of these persons were over 55 years old. There were three nonwhite persons hospitalized. Of the 32, three were residents of Webster, 27 were residents of Donora Borough, and two were workers on river boats that were passing by Donora.

The pattern of symptoms observed was essentially that described for the severely ill, a description of which appears elsewhere in this report.

This material was considered to be especially useful in that it contained data on objective findings which were lacking in most of the other material available to us. In the main, all patients in this group appeared to have in their clinical histories a component of cardiorespiratory disease. Thus, heart disease without failure was present 8 times, heart disease with failure 4 times, bronchial asthma 18 times, tracheobronchitis 7 times, pneumonitis twice, chronic bronchitis twice, and lung abscess once.

On physical examination of the lungs, rales were heard in nearly three-fourths of the cases, with a few instances of moist basal rales. Wheezing breath sounds were reported seven times and diminished breath sounds four times. Examination of the heart revealed a rapid rate in 11 instances, irregular rhythm in 5, increased area of cardiac dullness in 4, and cardiac murmurs in 4. Electrocardiograms, taken of six patients, contributed confirmatory evidence of heart disease in each. X-rays showed enlargement of the heart in five cases. X-rays also showed a few cases of silicosis, a few cases of pneumonitis, one case of bronchiectasis, and one of lung abscess. A selected group of X-rays are shown in figures 12–22.

Laboratory examinations showed nothing of significance which could be related to the acute illness allegedly due to the smog. All the findings could be attributed to the other disease conditions present.

The foregoing material pointed towards preexisting disease of the heart or lungs as a significant factor in the occurrence of severe smog illness. Other than this it failed to reveal a common factor or objective finding for these cases.

Case Descriptions

Case A–1, age 56, white, male, married, born in Czechoslovakia. In 1909 he came to Donora where he worked in the wire plant until his retirement 8 years ago because of heart disease.

His acute illness began in the morning of S-day, with dyspnoea, orthopnoea, and a productive cough. Since there was no improvement he was hospitalized on day No. 1.

The physical examination revealed that he was in acute respiratory distress. His head and neck were negative except for cyanosis of the mucous membranes. He manifested short inspirations and long expirations, scattered rales, and rhonchi bilaterally. The heart rate was rapid, and the rhythm irregular. The abdomen and extremities were negative and reflexes normal. The urine gave a 4+ reaction for albumin. Blood studies revealed 91 percent haemoglobin, 5,000,000 red blood cells, 17,000 white blood cells, with a differential count of 88 percent polymorphonuclear leukocytes, 10 percent lymphocytes, and 2 percent monocytes. Blood chemistry revealed 77 mg. of sugar, 26 mg. of nonprotein nitrogen, and 1.37 mg. of creatinine per 100 ml. of blood. Kahn and Kolmer reactions were negative. Temperature was 99° F., pulse rate was 92 and respirations 28.

He was placed in an oxygen tent upon admission to the hospital and was given 2 ml. of aminophyllin intramuscularly, sedatives, and a liquid diet. Within 2 days (on day No. 3) his dyspnoea improved, cough diminished, and cyanosis disappeared. Except for two episodes of vomiting during the first hospital day he was quite comfortable. He was discharged improved on the sixth hospital day, but remained extremely weak for more than one month afterwards. His clinical diagnosis was cardiac asthma.

According to his wife who was interviewed in connection with the present study, he had the following additional symptoms: A sweet taste, palpitation, headache, and hoarseness.

Case A–2, age 47, white, female, married, housewife, born in Czechoslovakia. She came to the United States in 1921 and lived in Donora since 1926.

She became acutely ill on the morning of S–day with a sense of painful constriction of her chest. The chest pain became worse that evening and she was unable to sleep. On day No. 1 she became dyspnoeic, orthopnoeic, cyanotic, and developed a nonproductive cough. Despite medical attention her symptoms persisted and she was hospitalized on day No. 2.

The physical examination was negative except for the chest which showed relatively short inspiratory and long expiratory movements. Respirations were labored and the rate increased. Moist rales and rhonchi were heard throughout both lungs. The urine examination of a catheterized specimen was negative except for a trace of albumin. Blood studies showed the following: Haemoglobin 91 percent, red blood cells 4,800,000, and white blood cells 11,000. The differential white count revealed the following: Polymorphonuclear leukocytes 63 percent, lymphocytes 29 percent, monocytes 2 percent, and eosinophils 6 percent. Kahn and Kolmer reactions were negative. Temperature was 98.6° F., pulse rate 120 and respirations 32.

She was placed in an oxygen tent and 2 cc. of aminophyllin were administered intramuscularly every 4 hours for the respiratory distress. In addition, adrenalin and sedatives were ordered as needed. For the cough, 1 dram of elixir of terpin hydrate with codeine every 4 hours was prescribed.

She vomited clear fluid several times during the first hospital day. She then made a rapid recovery. Her dyspnoea, orthopnoea, and cyanosis subsided after the second hospital day but her cough persisted and became productive. She was discharged on the seventh hospital day feeling greatly relieved. Her discharge diagnosis was tracheobronchitis and bronchial asthma.

Her previous history was negative except for bronchial asthma which was said to be aggravated by smog.

In an inteview at a later date the patient stated that she also had the following complaints during the acute illness: She detected a foul odor; had an acid taste, headache, and weakness. The weakness persisted for 2 weeks.

Case A–3, age 31, female, Negro, married, housewife, was born in Donora where she had always lived.

Her illness began on S-day with a sweet taste, dryness of the throat, and a productive cough which remained constant over days Nos. 1 and 2. During the night of day No. 2 she developed a retrosternal burning sensation, dyspnoea, and orthopnoea. On day No. 3 these symptoms persisted despite medical attention and she also developed abdominal pain, nausea and vomiting, chills, and weakness. Since she did not improve, she was hospitalized on November 3 (day No. 7).

Physical examination revealed a young, adult Negro female apparently not in severe distress. The head and neck were negative. Her chest expansions appeared reduced. Rales of unspecified type were heard throughout both lungs. Heart sounds were normal in rate and rhythm. Her abdomen showed marked tenderness throughout, and no visible or palpable masses were found. Her extremities were negative. Her urine was normal except for a 3+ sugar which may have been due to intravenous glucose therapy. Blood studies showed 81 percent haemoglobin, 4,500,000 erythrocytes, and 6,000 leukocytes of which 57 percent were polymorphonuclear leukocytes, 42 percent lymphocytes, and 1 percent monocytes. Her temperature was 99° F., pulse rate 88, and respirations were 22.

Her treatment consisted of 1,000 ml. of 10 percent glucose with normal saline solution, plus 100 mg. of thiamine chloride, sedatives, and a liquid diet. During the first two hospital days her dyspnoea subsided but she continued to vomit intermittently. On the third hospital day she was discharged improved, with a diagnosis of gastroenteritis.

Her previous history was negative.

Case A–4, age 68, white, female, widow, housewife, was born in Scotland.

She became ill in the evening of day No. 2 with dyspnoea, mild precordial pain, cough, and anorexia. She was hospitalized the same night.

Physical examination revealed a white, elderly female who was extremely dyspnoeic. Her head and neck were negative except for cyanosis of the mucous membranes. Her chest was barrel-shaped. Expirations were prolonged and wheezing. Faint crepitant rales were heard. The heart was enlarged to the left, and heart sounds were weak and distant, with no murmurs. The abdomen was distended and there were no visible or palpable masses. A catheterized urine specimen was acid in reaction, had a specific gravity of 1.032, a 2+ albumin, 4+ sugar, a trace of acetone, 2+ leukocytes, 1+ hyaline casts and 1+ finely granular casts. Blood studies showed 78 percent haemoglobin, 4,400,000 red blood cells, 8,000 white blood cells, of which 73 percent were polymorphonuclear leukocytes, 26 percent lymphocytes, and 1 percent monocytes. The blood chemistry results were: 286 mg. of sugar, 21 mg. of nonprotein nitrogen, and 2 mg. of creatinine per 100 ml. of blood. The carbon dioxide combining power was 62 volumes percent. Kahn and Kolmer reactions were negative. Her temperature was 98° F., pulse rate 88, and respirations 28. Her blood pressure was 150/92.

The patient was placed in an oxygen tent upon admission and was given 100,000 units of penicillin every 6 hours which was alternated with 50,000 units of streptomycin every 6 hours. She was also given opiates and placed on a liquid diet.

The dyspnoea, precordial pain, cough, and cyanosis disappeared within 3 days. The blood sugar was brought under control by the use of diet and administration of 15 units of insulin three times daily. She was discharged improved on the thirty-sixth hospital day. Her clinical diagnosis was diabetes mellitus.

Her previous history was negative.

Case A–5, age 53, white, male, single, was born in the United States and employed in the steel plant in Donora.

The patient was admitted to the hospital at 2:30 a. m. on day No. 3, a few hours after the onset of the illness, with the following complaints: Dyspnoea, orthopnoea, headache, abdominal pain, and cough.

Physical examination showed an adult white male in acute respiratory distress with marked activity of the accessory muscles of respiration. He had a staring expression with constricted pupils which were equal and responded to light and accommodation. His face had a "dusky" pallor with a deep cyanosis of the mucous membranes. He had a "barrel chest" which appeared to be fixed in inspiration. Breath sounds were not audible but fine rales were heard throughout both lungs. The heart sounds appeared feeble, rapid, and irregular. The abdomen had generalized tenderness. Extremities appeared cool and moist. The urine was negative except for a 1+ albumin. Blood studies were as follows: Haemoglobin 88 percent, erythrocytes 4,500,000, leukocytes 6,000. The differential white blood cell count showed 83 percent polymorphonuclear leukocytes, 17 percent lymphocytes and a slight anisocytosis was recorded. Kahn and Kolmer reactions were negative. His temperature was 97.6° F., pulse rate 120 and respirations 40.

The management of the case consisted of oxygen therapy, the administration of antihistaminics and a cough mixture. A few hours after admission the patient vomited a large amount of brownish fluid and undigested food. On the following day his dyspnoea subsided considerably, and his cough became productive of a thick purulent sputum. On the eighth hospital day he was discharged improved but was still coughing. His discharge diagnosis was bronchial asthma.

His previous history was negative.

Case A–6, age 54, white, male, married, was born in Jugoslavia. He came to the United States in 1912. He moved to Donora in 1929 where he was employed as a laborer in the steel plant.

His present illness began suddenly with dyspnoea, orthopnoea, and coughing on day No. 1 while sleeping at home. After receiving symptomatic treatment at home for two days without improvement, he was hospitalized on day No. 3.

The physical examination showed the head and neck to be negative except for cyanosis of the mucous membranes. Respirations were increased and labored with shortened inspirations and lengthened expirations. Scattered rales and rhonchi were heard throughout both lung areas. The heart was rapid and regular with no murmurs.

The abdomen and extremities were negative and reflexes were physiological. A voided urine specimen was negative except for a trace of albumin, a few leukocytes and an occasional erythrocyte. The blood findings included: 84 percent haemoglobin, 4,500,000 erythocytes, 6,000 leukocytes with a differential count of 72 percent polymorphonuclear cells, 24 percent lymphocytes, 2 percent monocytes and 2 percent eosinophils. Kahn and Kolmer reactions were negative. The temperature was 100° F., the pulse rate 140, the respirations 40. The blood pressure was 160/80. X-ray of the chest taken on the seventh hospital day showed: A normal heart; old healed fractures of ribs 8 and 9 on the right; and evidence of bronchiectasis.

The patient was placed in an oxygen tent and was given adrenalin. On the second hospital day a cough developed productive of blood-tinged fluid for which one dram of elixir of terpin hydrate with codeine was prescribed. In addition, he received 300,000 units of penicillin twice daily for 3 days.

The temperature dropped to 98.3° F. on the second hospital day, respirations decreased to 20 on the third hospital day and the pulse rate dropped to 80 on the fourth hospital day. On the fourth hospital day he was removed from the oxygen tent because of the disappearance of dyspnoea, orthopnoea, and cyanosis. On the sixth hospital day he was discharged improved. His discharge diagnosis was tracheobronchitis and bronchial asthma.

His previous history was negative except for bronchial asthma of several years' duration.

The patient, in a subsequent interview, reported that he had the following additional symptoms during his acute illness: A sweet taste for several hours, epigastric distress for 2 weeks, lack of appetite for 1 week and extreme weakness for 1 month.

Case A–7, age 57, white, male, widower, was born in Donora where he had always lived. He was employed as an accountant at the steel plant.

His illness started suddenly at 6 p. m. of day No. 2 while at home, with headache, sore throat, dyspnoea, orthopnoea, retrosternal constriction, and a dry cough. This episode lasted for 1 week and left him so weakened that he was unable to return to work. On December 7, 1948, he had a severe attack of dyspnoea, orthopnoea, generalized precordial pain, and coughing which required his being hospitalized on December 9.

The physical examination at that time revealed that he had severe dyspnoea and orthopnoea. His skin was pale, cool and moist, and his lips were intensely cyanotic. His pupils were equal and round, and reacted promptly to light and accommodation. The blood vessels of his neck were enlarged and pulsating visibly. The accessory muscles of respiration of the neck and abdomen were contracting vigorously while his chest appeared fixed in inspiration. His respirations were labored and rapid. "Discrete coarse" rales were discernible throughout both lungs. Heart sounds were distant, feeble, and rapid. The area of cardiac dullness was increased to the left. A soft systolic murmur, which was best heard at the apex, was transmitted up into the axilla. His blood pressure was 150/80. His abdomen was negative. There was a moderate amount of pitting oedema of the ankles. The urine was negative except for a trace of albumin and 1+ hyaline casts. Blood studies showed 84 percent haemoglobin, 4,700,000 red blood cells, 7,000 white blood cells of which 79 percent were polymorphonuclear leukocytes, 20 percent lymphocytes, and 1 percent monocytes. There was moderate anisocytosis and moderate polychromasia. Blood chemistry results were: 100 mg. of sugar, 30 mg. of nonprotein nitrogen, and 2 mg. of creatinine per 100 ml. of blood. Kahn and Kolmer reactions were negative. His temperature was 97° F., pulse rate 106, and respirations 26.

A chest X-ray, taken on the seventh hospital day, showed the following: Heart enlarged; old healed fractures of ribs 5, 6, 7, and 8 on right; lungs normal.

His clinical course was a stormy one presenting many problems. It was necessary for him to remain in the oxygen tent, which he could tolerate only a few hours at one time. He would become very apprehensive, restless, and somewhat confused. His dyspnoea, orthopnoea and precordial pain continued and he developed nocturnal paroxysmal attacks of dyspnoea despite the use of oxygen therapy, morphine, sedatives, and antihistaminics.

Starting with his seventeenth hospital day he was given digitalis. He also received 2 ml. of a mercurial diuretic daily for 5 days and then 2 ml. on alternate days. He also was placed on a salt-free diet. His ankle oedema disappeared and his pulse appeared stronger and slower.

He ran an afebrile course except for the afternoon of the forty-seventh hospital day when his temperature rose from a morning low of 98° F. to 101.2° F. with a rise of the pulse rate to 110. He was given 300,000 units of penicillin intramuscularly daily for four days. Meanwhile, the temperature dropped to 98° F. the following morning and he continued afebrile thereafter. His cough, which at first was nonproductive, persisted and became productive of a moderate amount of purulent sputum before it finally subsided.

The patient was discharged on the seventy-fourth hospital day.

His previous history was negative except that he had been known to have had arterial hypertension.

Case A–8, age 69, white, male, married, was born in Czechoslovakia. He came to the Donora area 46 years before and had been employed as a coal miner until his retirement in 1946.

His acute illness began on the morning of S-day with retrosternal burning, retrosternal pressure, and epigastric distress. On the following day he developed a dry cough which after several hours became productive of a thick gray tenacious sputum. On day No. 2 he became dyspnoeic and was attended by a physician. His dyspnoea and cough persisted and 8 days later he was hospitalized.

Physical examination revealed the head and neck to be negative except for slight cyanosis of the lips. The respiratory rate was rapid with shortened inspirations and lengthened expirations. The lungs showed moist rales throughout. There was no evidence of consolidation. The heart appeared slightly enlarged to the right with an irregular rhythm. No murmurs were heard. The abdomen and extremities were negative and the reflexes were physiological. The urine was negative except for a 3+ albumin and many erythrocytes. Blood findings were as follows: Haemoglobin 78 percent, red cells 4,100,000, and white blood cells 10,000. The differential white blood cell count revealed 71 percent polymorphonuclear leukocytes, 25 percent lymphocytes, 2 percent monocytes, and 2 percent eosinophils, with a slight anisocytosis present. The nonprotein nitrogen was 55 mg. and the creatinine was 1.77 mg. per 100 ml. of blood. Kahn and Kolmer reactions were negative. The temperature was 99.2° F., pulse rate was 84, and the respirations 20.

The roentgenological findings on admission were the following: The ascending aorta showed enlargement to the right; the heart was enlarged to the left (sabot type); and the lungs showed early nodular silicosis.

The patient responded rapidly to therapy which consisted of oxygen inhalation, 2 ml. of aminophyllin intramuscularly every four hours, 300,000 units of penicillin daily, sedatives and cough mixture. His dyspnoea and cyanosis diminished on the second hospital day, but his cough persisted for 6 days. He was discharged improved on the eighth hospital day with the diagnosis of acute tracheobronchitis.

His past history indicated that he had bronchial asthma for at least 20 years.

During an interview three months subsequently, the patient stated that he still had a sense of retrosternal burning and pressure.

Case A–9, age 63, white, male, widower, was born in Czechoslovakia. In 1905 he arrived in Donora where he had been employed as a laborer in the steel plant since that time.

He became sick on day No. 1 while at home, with dyspnoea, retrosternal constriction, a nonproductive cough, and nausea. Since he did not improve, he was hospitalized on day No. 4 at 2:30 p. m.

The physical examination revealed a dyspnoeic, white male who was coughing at intervals. His head and neck were negative except for cyanosis of the mucous membranes. In addition the tongue was coated. His chest was barrel-shaped and respirations were rapid and labored. Sibilant rales were heard throughout the lung fields. The heart rate was rapid and the rhythm regular. Heart sounds were distant and muffled and the heart appeared enlarged to the left. The abdomen was distended without any visible or palpable masses. The extremities were negative and reflexes were physiological. The urine was negative. Blood studies revealed 95 percent haemoglobin, 4,900,000 erythrocytes, and 8,000 leukocytes of which 80 percent were

polymorphonuclear cells, 12 percent lymphocytes, 5 percent monocytes, and 3 percent eosinophils. His temperature was 99.6° F., pulse rate 112, respirations 30, and blood pressure was 140/86.

The patient was placed in an oxygen tent and given injections of adrenalin every four hours. He received cough mixtures and sedatives. The dyspnoea, chest pain, and cyanosis diminished considerably by the fifth hospital day. His cough became productive of purulent sputum. His initial hospital period was afebrile, but on the fourth hospital day he developed an evening temperature elevation to 101° F. which dropped to normal the following morning. On the fifth hospital day the evening temperature rose to 102.2° F. He was placed on 50,000 units of penicillin every three hours with sulfonamides. By the 11th hospital day there no longer was an evening temperature elevation and his cough had subsided. He was discharged improved on the 13th hospital day with the diagnosis of bronchial asthma.

His previous history indicated that he had bronchial asthma which was aggravated by fog and smoke.

In a subsequent interview the patient claimed that since the acute illness he had had several recurrences of cough and dyspnoea associated with fog.

Case A–10, age 38, male, white, married, was born in Donora where he had always lived. He was employed at the wire plant.

He became ill on the night of day No. 2 with chest pain while at work. He continued to work and his pain ceased without medical attention. During the night of day No. 4 while at work he had another attack of severe chest pain which was accompanied by dizziness. He was given a hypodermic injection at the plant and was hospitalized.

Physical findings were negative except for injection of the eyes and throat and a "doubtful evidence of consolidation in the right lung base." His urine was negative. Blood studies were as follows: 78 percent haemoglobin, 4,700,000 red blood cells, 7,000 white blood cells, with 55 percent polymorphonuclear leukocytes, 38 percent lymphocytes, 5 percent monocytes, and 2 percent eosinophils. There was 1 normoblast per 100 white blood cells, slight anisocytosis, slight hypochromia, slight polychromasia, and slight basophilic stippling. His temperature was 98° F., pulse rate 116, and respirations 20. Oxygen and sedatives were given.

He was discharged improved the following day with the diagnosis of bronchial asthma.

His previous history was noncontributory.

Case A–11, age 48, white, male, married, was born in the United States and lived in the Donora area 42 years. He was employed as a coal miner and truck driver.

His acute illness began at 1:30 p. m. on day No. 5, with pain in the left shoulder and left chest which radiated to the back. The pain was sufficiently intense to require opiates for relief. He was admitted to the hospital later the same day.

The physical examination of the head and neck was negative. On the left side the chest appeared limited in expansion. No rales were heard. The heart had a normal rate and rhythm with no murmurs. the urine was negative. Blood studies showed 98 percent haemoglobin, 5,000,000 red blood cells, 8,000 white blood cells of which 66 percent were polymorphonuclear leukocytes, 32 percent lymphocytes, and 2 percent monocytes. The temperature was 98.4° F., pulse was 88, and respirations 20. X–ray film of the chest on admission was negative.

On a regimen of rest and sedation his pain disappeared within three days. He was discharged improved on November 5 (day No. 9). His diagnosis on discharge was bronchial asthma.

His previous history was negative except for dyspnoea associated with fog and smoke.

In a subsequent interview, 3 months later, he stated that in addition to the symptoms enumerated above he had had the following during his acute illness: Sweet taste, burning of the throat, cough productive of black tenacious sputum, dyspnoea, orthopnoea, pain along both costal margins, nausea, vomiting, chills, headache, weakness, dizziness, and aching of the extremities. During this interview he claimed that he still had dyspnoea on exertion and costal margin pain.

Case A–12, age 61, white, male, widowed, was born in Austria. He arrived in the United States in 1907, and since 1932 lived and worked in Donora. He was employed as a metal drawer in the zinc plant.

His illness began while at home at 7 p. m. on day No. 2 with dyspnoea, orthopnoea, constriction of the chest, cough, backache, and pain in right upper abdomen. Since his symptoms persisted despite medical attention, he was hospitalized on day No. 4.

Physical examination revealed a well-nourished, well-developed, adult white male with dyspnoea. His head and neck were negative except for cyanosis of the mucous membranes, pallor of the skin, and injection of the pharynx. The chest appeared to be fixed in inspiration; breath sounds were not audible, and "rales of all types" were heard. The heart rate was rapid. The rhythm was irregular and heart sounds were distant. The abdomen was distended with no visible masses or herniation. There was tenderness in the right upper abdominal quadrant and over McBurney's point. The extremities were negative and reflexes were physiological. The urine was negative. Blood studies revealed 98 percent haemoglobin, 5,000,000 erythrocytes, 7,000 leukocytes with a differential count of 63 percent polymorphonuclear cells, 27 percent lymphocytes, 4 percent monocytes, and 6 percent eosinophils. The temperature was 97.4 F., pulse rate 98 and respirations 20. The blood pressure was 110/80.

The patient was given antihistaminics, 1 dram of elixir of terpin hydrate with codeine every 4 hours, 300,000 units of penicillin daily, and 100 mg. of ascorbic acid three times daily. He was placed on a fat-free diet.

His improvement was gradual. The abdominal pain subsided on the second hospital day. His dyspnoea, cough and cyanosis although improved, were still present on the ninth hospital day, the day of his discharge. The diagnosis on discharge was bronchial asthma and chronic myocarditis.

The previous history was negative except that he said that he had bronchial asthma.

In a subsequent interview three months later the patient claimed that he also had had the following symptoms during his acute illness: Smarting of the eyes, lacrimation, and sore throat.

Case A–13, age 66, white, female, married, housewife, was born in the United States.

The patient was admitted to the hospital 2 a. m. of day No. 4 complaining of dyspnoea and nausea "which begun during the smog."

Physical examination showed an obese, white female apparently very dyspnoeic. Her neck was short and there was marked retraction of both the infra- and supra-clavicular spaces. There was a moderate cyanosis of the mucous membranes. The urine showed 4+ albumin, 3+ granular casts and 2+ hyaline casts. Blood studies disclosed 84 percent haemoglobin, 4,600,000 erythrocytes, 12,000 leukocytes of which 87 percent were polymorphonuclear cells, 10 percent lymphocytes, and 3 percent monocytes. The blood chemistry results were 91 mg. of sugar, 50 mg. of nonprotein nitrogen and 2.3 mg. of creatinine per 100 ml. of blood. The CO_2 combining power of the blood was 64 volume percent. Kahn and Kolmer reactions were negative. Her temperature was 99.5° F., pulse was 112, and respirations were 36. Her blood pressure was 160/90.

Upon admission the patient was given oxygen therapy. A few hours after admission she appeared to have lost consciousness, regaining consciousness after several minutes. She was very dyspnoeic for more than a week, requiring almost continuous oxygen therapy. She was placed on a salt-free diet. Examination of urine on the seventh day showed 1+ albumin, 1+ granular casts and a few hyaline casts.

She was discharged improved on the 14th hospital day with the diagnosis of bronchial asthma.

Her previous history was recorded as noncontributory.

Case A–14, age 62, white male, married, born in Italy, was employed as a mill worker in Donora.

His acute illness began at 5:30 p. m. on day No. 2 with dyspnoea and coughing. The dyspnoea was accompanied by a feeling of suffocation and constriction of the chest. Two hours later he was admitted to the hospital.

Physical examination showed the head and neck to be negative except for injection of the eyes and throat. Respirations were increased and labored. Inspirations were short and expirations long and wheezing. The motion of the chest appeared limited. The heart was normal in rate, rhythm and tone quality, with no murmurs. The abdomen and extremities were negative. Reflexes were physiological.

The examination of urine was negative. Blood study results were as follows: Haemoglobin 84 percent; red blood cells, 4,500,000; white blood cells 8,000. The differential count showed 72 percent polymorphonuclear leukocytes, and 28 percent lymphocytes. The temperature was 99° F., pulse rate 80, and the respirations 24.

He was treated with tincture of benzoin inhalations, antihistaminics, adrenalin, and sedatives. On the following day the inhalation therapy was discontinued since his dyspnoea and chest pain had subsided. He made an uneventful recovery and was discharged on the fifth hospital day.

His clinical diagnosis on discharge was bronchial asthma.

His previous history was negative.

Case A–15, age 60, white, male, widowed, was born in Poland. He came to the United States in 1908. He lived in Donora since 1916 and was employed as fireman in the zinc plant.

He suddenly became ill at midnight of day No. 2 with dyspnoea, orthopnoea, constriction of the chest, and a productive cough while at home in bed. On the advice of his attending physician the following morning he was taken to the adjacent town of Monessen. Here his symptoms subsided abruptly, but upon his return to Donora on day No. 4 his symptoms recurred. Since he appeared not to improve he was hospitalized on day No. 6.

Physical examinations revealed a well-developed white male with dyspnoea. His head and neck were negative except for pallor of the skin and cyanosis of the mucous membranes. There was a marked visible pulsation of the enlarged blood vessels of the neck. The chest was fixed in inspiration. Breath sounds were not audible and expiratory wheezes and rales were heard through both lung fields. Heart sounds were distant and the heart rate was rapid. No murmurs were heard. The urine was negative except for 1+ albumin. Blood studies showed 78 percent haemoglobin, 4,400,000 red blood cells, 7,000 white blood cells of which 65 percent were polymorphonuclear leukocytes, 32 percent lymphocytes and 3 percent were monocytes. Kahn and Kolmer reactions were negative. His temperature was 101.8° F., pulse rate 92 and respirations 22.

On admission the patient was placed in an oxygen tent and was administered 100,000 units of penicillin, which was followed by 50,000 units every three hours. He also received antihistaminics. The following day his dyspnoea and cyanosis appeared diminished and his temperature dropped to 98.8° F. and his pulse rate to 84. Oxygen therapy was discontinued after the third hospital day. He continued to cough at intervals and on the fourth hospital day he apparently developed a mild case of herpes simplex about the perioral area. On the seventh hospital day he was discharged as improved with a diagnosis of bronchial asthma.

Three weeks after his hospital discharge he was forced to discontinue working because of extreme weakness. On December 24, he had another attack of dyspnoea, substernal constriction and coughing and was readmitted to the hospital on December 25. Physical findings and laboratory results were essentially the same as those of the previous admission. His temperature was 99.2° F., pulse rate 104, and respiration 24.

He was placed in an oxygen tent, given antihistaminics, and 1 dram of elixir of terpin hydrate with codeine every 4 hours. He remained in the oxygen tent 3 days and his dyspnoea subsided. His cough which was productive of a purulent sputum gradually diminished. He was discharged on the sixth hospital day with a diagnosis of bronchial asthma and myocardial decompensation.

In an interview at a later date, in connection with this study, the patient claimed that during the first illness he had had these additional symptoms: Smarting of the eyes, lacrimation, nasal discharge, and hoarseness.

Case A–16, age 66, white, male, married, was born in France. He lived in the Donora area for the past 30 years where he was employed as a laborer in the steel plant.

He became ill on the morning of day No. 2 with dyspnoea, orthopnoea, cough, abdominal pain and headache. He was hospitalized at 1:45 p. m. of the same day because of the severity of symptoms.

Physical examination revealed an elderly man in acute respiratory distress. The face appeared to have cyanosis of a grayish hue. The skin was cool and moist. The tongue was coated and the throat injected. Respirations were rapid and labored. Breath sounds were diminished and rales of all types were heard throughout the chest. Heart sounds were distant, the rate was rapid and the rhythm irregular. Abdominal muscles had a generalized rigidity and were tender. No rebound tenderness was elicited nor palpable masses noted. Extremities were negative and reflexes physiological. A voided urine specimen showed the following: reaction acid, specific gravity 1.020; albumin 2+; sugar negative; acetone trace; diacetic acid negative; leukocytes 1+; hyaline casts few; finely granular casts few; coarsely granular casts 1+; bacteria 4+. Blood studies revealed: haemoglobin, 102 percent; red blood cells, 5,300,000; white blood cells, 12,000, of which 78 percent were polymorphonuclear leukocytes, 21 percent lymphocytes, and 1 percent were monocytes. The results of blood chemistry analyses were as follows: sugar 77 mg., nonprotein nitrogen, 33 mg. and creatinine 1.58 mg. per 100 ml. of blood. Kahn and Kolmer reactions were negative. The temperature was 98.4° F., pulse rate 112 and respirations 32.

On admission the patient was given antihistaminics and was placed in an oxygen tent where he remained almost continuously until the sixth hospital day. He was given 300,000 units of penicillin daily after the second hospital day, since he developed a sore throat, a temperature of 101° F., and a pulse of 92, accompanied by a persistent productive cough. By the sixth hospital day his dyspnoea, orthopnoea, cyanosis, and sore throat and fever had disappeared, but he continued to cough and expectorate a gray purulent material. On the twenty-first hospital day he was discharged improved with a diagnosis of bronchial asthma and chronic myocarditis.

He had had bronchial asthma for several years. In 1946 he had a severe attack which required hospitalization. His previous history was negative otherwise.

Case A–17, age 59, white male, married, born in the United States, was hospitalized on day No. 3 with the complaint of dyspnoea.

His illness began on day No. 2 with dyspnoea, which was not relieved by the next day. On day No. 3 he also had cyanosis. He said that he had a similar attack 1 year ago, which he said was due to the fog. In the present attack he also developed headache.

The review of the systems was found to be negative except for the above.

On physical examination on admission he showed bilateral moist basal rales, moderate cyanosis of the fingernails, and a liver which, by percussion, was considered to be enlarged. His blood pressure was 128/96. On the second hospital day rales were still present, although diminished, and he seemed much improved. It was also noted that he had a small amount of oedema of the ankles, and orthopnoea. His symptoms disappeared on the next day, although a few rales still remained.

On the third hospital day his vital capacity was found to be 70 percent of normal. Circulation time tested on the third hospital day was 19 seconds (method used not known).

His temperature on admission was 100° F. and rose to 101° F. on the same day, dropping again the next day to normal, where it remained. Pulse and respiration were not remarkable.

He was treated with penicillin, sedatives, and antispasmodics.

It was observed that he developed a mild conjunctivitis, which responded to local therapy.

The red blood cell count was 4,800,000, white blood cell count 8,200, and haemoglobin 90 percent. The differential white blood cell count was: Polymorphonuclear neutrophils 66 percent, eosinophils 4 percent, lymphocytes 28 percent, and monocytes 2 percent. The blood chemistry was reported as follows: sugar 114 mg. percent, chloride 432 mg. percent, and nonprotein nitrogen 32 mg. percent. The carbon dioxide capacity was 46.3 volumes percent and subsequently was 40.0 volumes percent. The erythrocyte sedimentation rate was 22 millimeters at the end of one hour on the first hospital day. Routine urine analysis was normal. The electrocardiogram showed a left-sided cardiac preponderance.

X-ray taken on the first hospital day showed an enlarged heart and a tortuous aorta. The pulmonary parenchyma was normal.

He was discharged improved on the fifth hospital day with a diagnosis of acute pulmonary oedema and chemical pneumonitis.

Case A–18, age 56, white, male, was hospitalized on day No. 3. He complained of dyspnoea of 3 to 4 months' duration and said that while working on a boat near Donora his symptoms became worse. He also noted that he developed orthopnoea and retrosternal pain.

His previous history was negative, as was the review of symptoms referable to the various systems of the body.

On physical examination he was found to have mild dyspnoea, but he did not appear in distress. Examination of the lungs showed a few rhonchi throughout with exaggeration at the bases. His temperature, pulse, and respiration were normal.

He stayed in the hospital one day and felt well enough to leave the next morning. Wassermann and Kahn tests were negative. A chest X-ray taken on admission was negative.

His diagnosis on discharge was bronchitis.

Case A–19, age 53, white, male, was hospitalized on day No. 5 at 11 a. m.

He complained that on day No. 3 his illness began with dyspnoea, cough, and chest pain. The onset occurred while he was working on a river boat which was passing by Donora. He said that others on the boat were also affected but not as severely as he. He came to the hospital because his symptoms had not been relieved.

In a review of the systems it was found that they were all negative, except that he had had a chronic nonproductive cough for some time.

On physical examination on admission to the hospital he was found to have a few small rales at the posterior bases of the lungs. There was a soft systolic murmur at the apex of the heart. Blood pressure was 144/98. Otherwise all other findings were negative. His temperature, pulse, and respiration on admission were normal and remained so for the 2 days that he stayed in the hospital. Red blood cell count was 4,950,000, white blood cell count 5,750, haemoglobin 90 percent. The differential blood count showed 71 percent polymorphonuclear leukocytes and 29 percent lymphocytes. Routine urine analysis was negative. Wassermann and Kahn tests were negative.

X-rays taken on November 12 were read as negative.

Therapy consisted of antispasmodic drugs, expectorants, and sedatives. He improved under the therapy and was discharged a few days after admission with a diagnosis of acute laryngotracheitis.

Case A–20, age 8, white, male, resident of Donora for 3 years, was hospitalized on the night of day No. 3 with the complaint of chest pain.

His illness began on day No. 2 with cough and fever. He had a previous pneumonia in May 1948.

On physical examination on admission he appeared acutely ill. He showed fine rales in the upper lobe of the left lung and clubbing of the fingers. The findings were normal otherwise.

The red blood cell count was 4,560,000, white blood cell count 9,900, haemoglobin 84 percent. The differential white blood cell count was polymorphonuclear neutrophils 89 percent, eosinophils 1 percent, and lymphocytes 10 percent. The neutrophils dropped to normal on the fifth hospital day. The urine was negative except for a 1+ albumin on admission.

X-ray taken on the sixth hospital day, November 5, showed an infiltrative process in the left lung field.

He was treated with expectorants and penicillin.

He had a stormy clinical course with an extention of the pneumonic process, confirmed by chest X-ray taken on the tenth hospital day, November 9. His temperature on admission was 103.2° F., which rapidly dropped to normal on the third day. He had a chill on the fifth day, with a rise in temperature to 103.8° F. which dropped to normal the next day. The pulse was in proportion to the temperature. The signs in the lungs cleared during the latter few days of hospitalization. An X-ray taken on the sixteenth hospital day, November 15, showed complete clearing of the infiltrative process.

He was discharged improved on the sixteenth hospital day with a diagnosis of bronchopneumonia, left.

Case A–21, age 61, white, male, divorced, born in Spain and a resident of Donora for 24 years, was hospitalized on day No. 3 with the complaint of dyspnoea.

On physical examination he was found to be semicomatose and cyanotic. Examination of the chest showed rales throughout the lung fields and labored, limited chest expansions. The red blood cell count was 5,140,000, white blood cell count 12,800, haemoglobin 88 percent. The differential count showed 91 percent polymorphonuclear neutrophils and 9 percent lymphocytes. Urine analysis showed a trace of albumin and a trace of sugar. Kahn and Wassermann tests were negative. The electrocardiogram showed left axis deviation and indication of myocardial damage. The temperature was normal on admission and thereafter ran between 99° F. and 100° F., returning to normal on the eighth hospital day. The pulse was in proportion to the temperature.

A chest X-ray taken on the sixth hospital day was negative.

The therapy consisted of oxygen (tent) and antispasmodics, including adrenalin. He appeared improved by the ninth hospital day and was discharged 2 days later.

The clinical diagnosis was bronchial asthma, tracheobronchitis, and heart disease with failure.

Case A–22, age 58, Negro, male, widowed, born in the United States, janitor in the zinc plant, was hospitalized on day No. 3 with the complaint of dyspnoea.

He had a previous history of bronchial asthma.

On admission the physical examination findings were negative except for rales throughout the chest. His temperature was 99.6° F. and it rapidly returned to normal. The pulse varied directly with the temperature. The red blood cell count was 5,240,000, white blood cell count 7,500, haemoglobin 87 percent. The differential white cell count showed 77 percent polymorphonuclear neutrophils, 1 percent eosinophils, and 22 percent lymphocytes.

He was given antispasmodics and a rapid improvement was noted. He was discharged on the third hospital day with a diagnosis of bronchial asthma and tracheobronchitis.

Case A–23, age 47, Negro, male, married, steel plant worker, born in the United States, was hospitalized on day No. 4 after becoming ill on day No. 2.

On physical examination he was found acutely ill and semicomatose. The examination of the chest revealed a few scattered rales anteriorly and posteriorly, and limited expansion of the chest. The temperature was 102.2° F. on admission and dropped to normal the same day, where it remained. The pulse was in proportion to the temperature.

The red blood cell count was 4,480,000, white blood cell count 9,400, haemoglobin 78 percent. The differential blood count showed 78 percent polymorphonuclear neutrophils and 22 percent lymphocytes. The urine on admission showed 1+ albumin and 4+ sugar, and on the following day showed 4+ sugar. Kahn and Wassermann tests were negative.

The electrocardiogram showed left axis deviation and evidence of myocardial damage. Chest X-ray taken on the fourth hospital day was negative.

He was given penicillin and placed in an oxygen tent. He made a rapid recovery and was discharged on the third hospital day with a diagnosis of bronchial asthma and tracheobronchitis.

Case A–24, age 60, white, male, divorced, huckster, resident of Donora for 24 years, was hospitalized on day No. 3 with the complaint of dyspnoea of several hours' duration.

He had a previous history of bronchial asthma.

On physical examination he appeared acutely ill with severe dyspnoea and moderate cyanosis. Expansion of the chest showed limited movements with rales throughout the chest anteriorly and posteriorly. His temperature and pulse were normal.

The red blood cell count was 5,180,000, white blood cell count 8,600, haemoglobin 96 percent. The differential cell count showed 63 percent polymorphonuclear leukocytes, 2 percent eosinophils, 34 percent lymphocytes, and 1 percent monocytes. Analysis of the urine was negative.

He was given adrenalin, other antispasmodics, and oxygen by mask. He improved rapidly and was discharged on the second hospital day with a diagnosis of bronchial asthma.

Case A–25, age 70, white, male, married, storekeeper, resident of Donora for 34 years, hospitalized on day No. 2 with the complaint of dyspnoea and cyanosis.

He had a past history of bronchial asthma of several years' duration.

On physical examination he appeared acutely ill in a semicomatose state. He was cyanotic and markedly dyspnoeic. Examination of the chest showed rapid, labored respiratory movements and numerous

coarse rales and wheezes throughout. His temperature on admission was 100° F., where it remained for 2 days before dropping to normal. The pulse rate was 120 and dropped to normal after 2 days.

The red blood cell count was 5,120,000, white blood cell count was 10,700, haemoglobin 89 percent. The differential count showed 76 percent polymorphonuclear neutrophils, 2 percent eosinophils, and 22 percent lymphocytes. The urine showed 4+ albumin and a trace of sugar. Kahn and Wassermann tests were negative.

He was placed in an oxygen tent, and was given cardiac stimulants and penicillin. He improved rapidly and was discharged on the fourth hospital day.

His discharge diagnosis was acute tracheobronchitis and bronchial asthma.

Case A–26, age 64, white, female, widow, resident of Donora for 45 years, was hospitalized on day No. 4 with the complaint of dyspnoea.

Her illness began on day No. 3 with severe dyspnoea, substernal pain, and cough. She had had a mild degree of dyspnoea on exertion for some time previously and had had attacks of dyspnoea during foggy weather.

On physical examination there were found coarse rales and high-pitched expiratory breath sounds at both bases. The heart appeared normal and her blood pressure was 186/100. The remainder of the examination was negative. Her temperature was normal; her pulse was elevated to 100, where it remained throughout her hospital stay.

The red blood cell count was 3,550,000, white blood cell count 10,000, haemoglobin 84 percent. The differential white cell count showed 75 percent polymorphonuclear leukocytes, 4 percent eosinophils, and 21 percent lymphocytes. Macrocytosis was observed. Routine urine analysis was negative. The blood sugar was 90 mg. percent and nonprotein nitrogen 40 mg. percent. Kahn and Wassermann tests were negative.

An X-ray taken on the eighth day showed old healed pleurisy at left lower lobe with contraction of the left chest.

The therapy consisted of antispasmodics, expectorants, and oxygen. She improved on the third hospital day and was discharged on the ninth day. The discharge diagnosis was arteriosclerotic heart disease, hypertension, and pernicious anemia.

Case A–27, age 61, white, female, married, resident of Donora, was hospitalized on day No. 2.

Her illness began earlier the same day (day No. 2) with dyspnoea, cough, and retrosternal distress. She was a known cardiac with a previous history of repeated attacks of cardiac failure related to severe fog.

On physical examination she appeared extremely dyspnoeic with a moderate degree of cyanosis. Examination of the chest revealed fine rales at the bases. Her blood pressure was 120/70. The examination otherwise was negative. Temperature and pulse were normal on admission.

The red blood cell count was 5,130,000, white blood cell count 9,300, haemoglobin 100 percent. The differential cell count was as follows: polymorphonuclear leukocytes 67 percent, eosinophils 1 percent, lymphocytes 31 percent, and monocytes 1 percent. Analysis of urine on two occasions showed only traces of albumin. Wassermann and Kahn tests were negative.

The electrocardiogram showed low voltage and evidence of myocardial damage. X-ray of the chest taken on the tenth hospital day was negative.

She was treated with digitalis, antispasmodics, and sedatives. Her temperature rose to slightly over 99° F. the following day, and was irregular between 98° and 100° F. for the next 5 days, and then dropped to normal, where it remained. Her pulse and respirations were recorded as normal throughout her hospital stay. She improved rapidly and was discharged on the eleventh hospital day.

Her discharge diagnosis was acute tracheobronchitis, arteriosclerotic heart disease, and heart failure.

Case A–28, age 76, white, male, widower, born in Austria, resident of Donora, was hospitalized on December 20, 1948.

His illness began on day No. 3 with dyspnoea, orthopnoea, chest pain, cough, and cyanosis, all of which persisted and became worse.

His previous history was said to be negative.

On physical examination he showed limitation of chest expansion bilaterally. Expiratory wheezes and discrete moist rales were heard throughout the lungs. A harsh systolic murmur was heard over the entire precordium. Bilateral ankle oedema was present. His temperature on admission was normal, where it remained; his pulse rate varied between 90 and 100, and respirations between 25 and 40.

The red blood cell count was 4,400,000, white blood cell count 8,000, haemoglobin 78 percent. The differential count showed 76 percent polymorphonuclear leukocytes, 4 percent monocytes, and 20 percent lymphocytes. The urine showed a trace of albumin. Kahn and Klein tests were negative.

A chest X-ray taken on the fourth hospital day showed enlarged heart; exaggerated pulmonic markings with early nodulation suggestive of silicosis, and emphysema in the lower lobes.

Therapy consisted of oxygen (by tent), mercurial diuretics, digitalis preparations, antispasmodics, sedatives, and bed rest. He responded to the treatment. He appeared improved on the fourteenth hospital day and was discharged much improved on the eighteenth day.

The discharge diagnosis was arteriosclerotic heart disease and congestive heart failure.

Case A–29, age 65, white, male, widower, born in Czechoslovakia, resident of Webster, coal miner and zinc plant worker, was hospitalized on day No. 14.

His illness began on the morning of day No. 3 with dyspnoea, chest pain, and ankle oedema, which progressed after that date. He was a known bronchial asthmatic.

On physical examination he showed inspiratory and expiratory wheezes and a few discrete rales. Chest expansion appeared limited. His red blood cell count was 5,000,000, white blood cell count 10,000, haemoglobin 95 percent. The differential white blood cell count showed 86 percent polymorphonuclear leukocytes, 9 percent lymphocytes, 3 percent monocytes, and 2 percent eosinophils. His urine showed a slight trace of albumin and 4+ hyaline casts. Kahn and Kolmer tests were negative. His temperature, pulse, and respiration were normal and remained so throughout.

He was given digitalis, mercurial diuretics, antispasmodics, bed rest and limited fluids. He improved very rapidly and was discharged improved on the fifth hospital day. His diagnosis on discharge was bronchial asthma and cardiovascular-renal disease.

On December 3, 1948, he was readmitted to the hospital with the same complaints. Physical examination findings were essentially the same. In addition, cyanosis was observed. The urine showed a trace of albumin as in previous admission. Blood chemistry findings were: nonprotein nitrogen 46 mg. percent and creatinine 1.77 mg. percent.

His temperature on admission was normal and rose to 101° F. on the seventh hospital day. It then returned to normal on the following hospital day. The pulse was in proportion to the temperature.

An X-ray taken on the eleventh hospital day showed: Enlargement of the heart to the left with prominence of the aortic knob; healed fractures of ribs 7 and 8 on right side; emphysema at the left base; circumscribed infiltration in outer one-third of right lower lobe. Impression: Pneumonitis right lower lobe and emphysema. Another X-ray taken 9 days later showed a rarefied area in the upper portion of the pneumonic process previously noted. Impression: Lung abscess.

He was placed in an oxygen tent and given penicillin. He did not respond to the therapy but became progressively worse. He died at 10:45 p. m. on December 22, 1948.

Autopsy

Autopsy performed at 4:30 p. m. on December 23, 1948, showed the following:[8]

Heart.—The heart weighed 465 gms. and was moderately enlarged. The epicardium was smooth but presented on the anterior surface several milky patches of thickening. Tricuspids and pulmonary valves were grossly normal. The aortic leaf of the mitral valve presented a small patch of opaque sclerotic thickening, otherwise normal. The right anterior and the posterior leaflet of the aortic valve were slightly calcified and adherent to each other, causing a mild degree of stenosis. The major coronary branches appeared to be free of sclerosis and were

[8] The autopsy was performed by Dr. G. W. Ramsey, of Washington, Pa., and certain organs were brought to the National Institutes of Health for further study.

of normal caliber and were entirely patent. The myocardium appeared grossly normal on multiple sections.

Esophagus.—Grossly normal.

Trachea.—The trachea contained a small amount of regurgitated food material, probably due to purging after death. Its mucosa was not remarkable.

Lungs.—Both lower lobes were congested and oedematous. There was considerable emphysema in the left lower lobe. Both lungs on section contained numerous small black nodules 1 to 2 mm. in diameter. In both lungs, branches of the pulmonary artery were occluded with thrombi. The right lung was adherent to the thoracic wall along the anterior axillary line and also to the diaphragm. There were two separate cavities in the right lower lobe which were approximately 5 cm. in diameter. These cavities contained a thin purulent fluid. Portions of the cavity walls were of a greenish color. The bronchi contained a moderate amount of mucoid exudate.

Mediastinal Lymph Nodes.—The lymph nodes were enlarged, firm, and moderately anthracotic.

Liver.—The liver extended 5 cm. below the right costal margin. The surface of the liver was smooth, and the capsule showed no evidence of thickening. The cut surface of the liver showed passive congestion markings.

Spleen.—The spleen was moderately enlarged, and the cut surface was dark red apparently due to congestion.

Kidneys.—The capsules of both kidneys stripped easily and left a smooth surface. The cut surface of the kidneys was dark red due to congestion. The pelves contained a moderately increased amount of fat.

Aorta.—The thoracic aorta was of normal caliber and presented only a few small atheromatous streaks in the intima.

Microscopic Findings

The microscopic findings were as follows: [9]

Lung.—The sections exhibit a predominating acute change which in places is complicated also by a mild chronic type of reaction. The acute change is characterized by a large focal area of compact pus cells in which the lung is completely destroyed. The area is surrounded in part by a wall of fibrin, fibrous tissue and externally by compressed pulmonary parenchyma which often contains many vascular channels distended with blood. Some of the fibrous tissue component of the wall is identified as part of the interlobular septa. Other than for the presence of scattered bluish cocci, there is nothing to suggest a specific etiology of the abscess.

Elsewhere, the alveoli are filled with masses of leukocytes, leukocytes and fibrin, or with solid plugs of fibrin. Here the alveolar walls are infiltrated with a variety of inflammatory cells. In places they are thickened also by mild proliferation of local tissue elements consisting primarily of histiocytes and large mononuclear cells. Occasionally, this proliferative process extends into the adjacent alveolar space tending to replace the fibrin plug. Thus, there is evidence of early organization.

The acute process is manifested also by the presence of oedematous precipitate in some of the alveolar spaces. Some spaces contain also a few widely scattered erythrocytes. These features are most pronounced in the more air-containing portions of the lung, especially where the alveolar wall capillaries are congested and frequently ruptured. In general, however, oedema and haemorrhage are not prominent features.

The bronchioles included in the sections occasionally contain small masses of leukocytes and desquamated epithelial cells. The walls of those passages are often thickened with infiltrated inflammatory cells which extend into the peribronchiolar pulmonary tissue. In addition, the vascular channels, particularly in the areas of most acute change, give evidence of endarteritis and periarteritis which narrows the lumina and thickens the walls of these passages.

The chronic changes consist of cellular proliferation of the parenchymal elements which thickens the alveolar walls. In addition, there is also a fibrous thickening of the pleura and many of the interlobular septa. In consequence, many of the alveoli are distorted, being often greatly enlarged with rupture of the alveolar walls and the formation of emphysematous spaces.

There are local deposits of black pigment which occur in the perivascular and peribronchiolar tissue, as isolated masses in the alveolar walls, interlobular septa, and thickened pleura. Many such deposits show little or no associated tissue reaction. They are present as isolated masses in a zone of simple, unstimulated connective tissue. Other deposits, however, are accompanied by an appreciable local tissue reaction, proliferative in type with a minimum of connective tissue. Hyalinization is not detected. Thus, there is evidence that the deposits of dust pigment have a mild irritating capacity, but in no case comparable to that resulting from the pulmonary deposition of appreciable quantities of free silica. The character and degree of dust reaction present in the sections submitted do not warrant a diagnosis of anthracosilicosis.

In addition to the large local deposits of black pigment described above, the dust occurs also as isolated particles within macrophages widely scattered throughout the alveolar wall and in many of the alveolar spaces. Such particles are not accompanied by any particular reaction other than might be accounted for by reason of the acute and chronic process previously described.

Heart.—The epicardium presents a mild increased thickening due to proliferation of connective tissue elements, but otherwise without detectable inflammatory reaction. The underlying adipose tissue is normal in amount and without change. The vascular channels are distended with blood. Their walls are thin. The myocardial bundles are generally normally disposed. However, some are widely separated by increased amounts of connective tissue which in some places is fibrous in character. This process is suggestive of a mild degree of scarring. The muscle nuclei are slightly enlarged which is also suggestive of some degree of hypertrophy. The coronary vessels contained in the single section submitted do not reveal significant changes in their wall.

Aorta.—The aorta is without significant abnormality.

Spleen.—The spleen exhibits focal small and irregular areas of degeneration in the subcapsular zone of the pulp. These areas are without appreciable leukocytic reaction. The lymph follicles are small, and not unduly active. The sinusoids are frequently dilated, but most are empty.

Liver.—The liver reveals moderately advanced central degeneration of the lobules, probably the result of chronic passive congestion. Elsewhere, there is mild fatty metamorphosis of the liver cells.

Kidney.—The cortex exhibits focal scarring accompanied by very mild lymphocytic infiltration. The scars contain occasional glomeruli in various stages of sclerosis. Some glomeruli are completely hyalinized. There is an occasional hyaline cast in some of the tubules, located principally in the medullary substance. The vascular channels are usually thin-walled and widely patent.

The anatomical diagnosis was as follows: cardiac hypertrophy; aortic stenosis, slight; myocardial fibrosis, slight; arteriosclerosis, generalized, minimal; pulmonary emphysema, marked; pulmonary anthracosis, moderate; lung abscess; bronchiectasis; bronchopneumonia; multiple infarcts of spleen, small; arteriosclerosis of kidney, slight; passive congestion of liver and kidney. (Photographs of microscopic sections appear in figures 40 to 43.)

Spectrographic Analyses

Spectrographic analyses were made of lung and bone. Ten-gram samples of tissue were weighed into flasks and acid-ashed with nitric and sulfuric acids. Portions of the dry residual ash were placed in the cupped part of the graphite electrode and exposed spectrographically. The entire range of the spectrum from the infrared to far ultraviolet was obtained with each specimen. The spectrograms were then carefully examined for all lines of any prominence. With reference to the findings described below, it may be noted that those elements to which toxic qualities could be ascribed were, in all cases, present in trace amounts only. It is exceedingly doubtful if these amounts could have any pathological-physiologic effect.

[9] The microscopic study was made by Dr. Arthur J. Vorwald, Director, The Edward L. Trudeau Foundation, and Consultant to the Public Health Service.

Figure 12.—*Case A-8:* Chest X-ray taken November 6, 1948.

Figure 13.—*Case A-20:* Chest X-ray taken November 5, 1948.

Figure 14.—*Case A-20:* Chest X-ray taken November 9, 1948.

Figure 15.—*Case A-20:* Chest X-ray taken November 15, 1948.

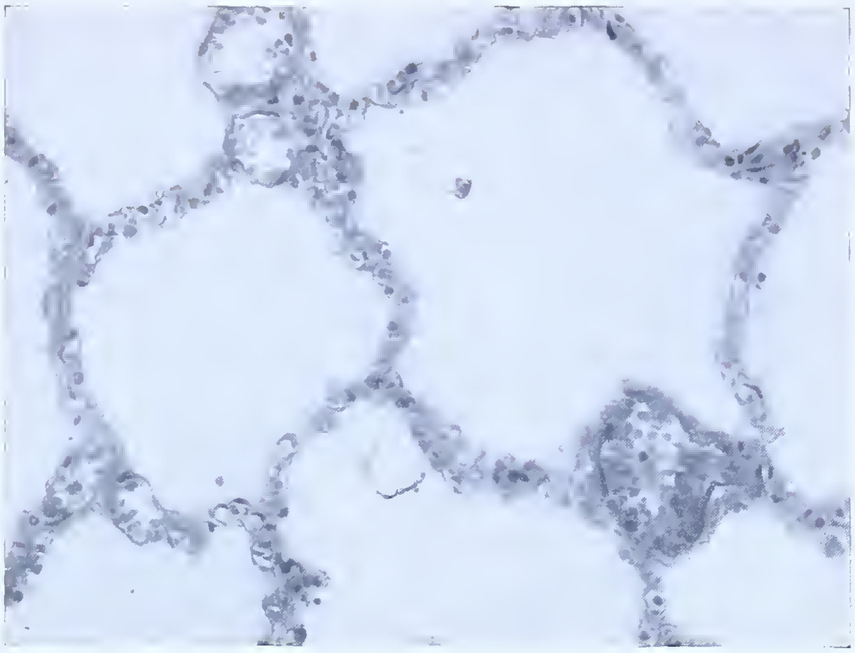


Figure 26.—*Case No. 2:* The alveolar structure from a portion of the lung without significant abnormality. The alveolar capillaries are only slightly dilated. The walls are thin and the alveoli are empty. X150.

Figure 27.—*Case No. 2:* The alveoli in an area with focal oedema. The spaces are filled with oedematous precipitate and a few scattered inflammatory cells. The walls are only slightly thickened by leukocytes and mononuclear cells. X150.

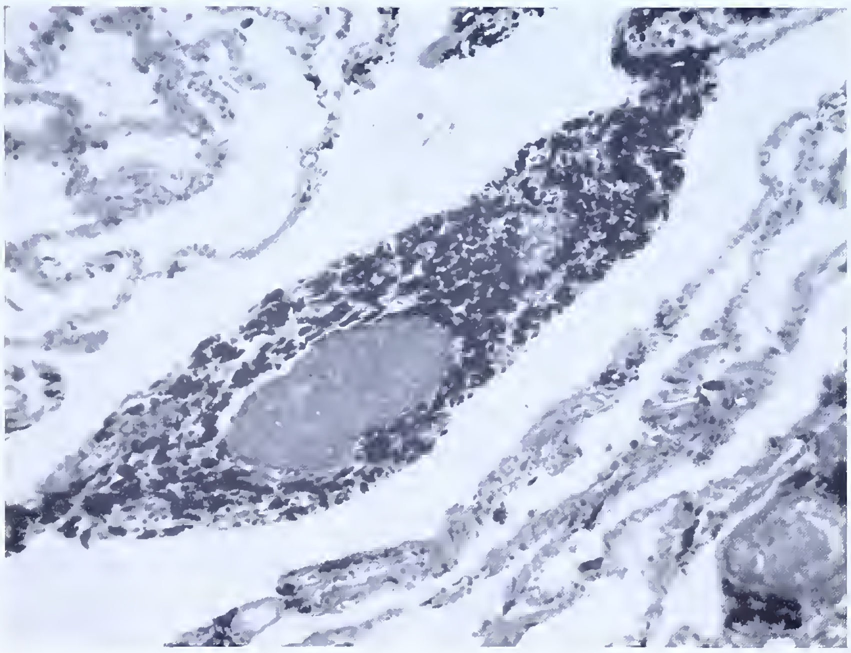


Figure 28.—*Case No. 2:* Perivascular accumulation of black pigment which is accompanied only by a very mild inflammatory reaction and therefore the dust is classified as inert. X150.

Figure 29.—*Case No. 2:* Alveolar walls containing particles of black dust isolated in the connective tissue framework and within the cytoplasm of macrophages. X900.

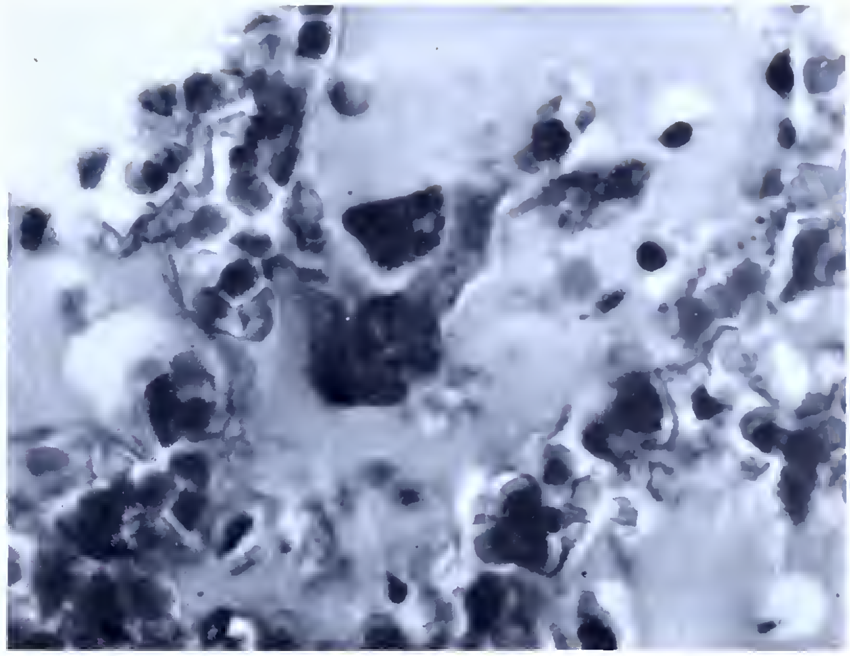


Figure 30.—*Case No. 3:* The alveolar wall is thickened by proliferation of local histiocytes and infiltration of inflammatory cells. The air spaces are distorted. Minute particles of pigment are scattered throughout. X150.

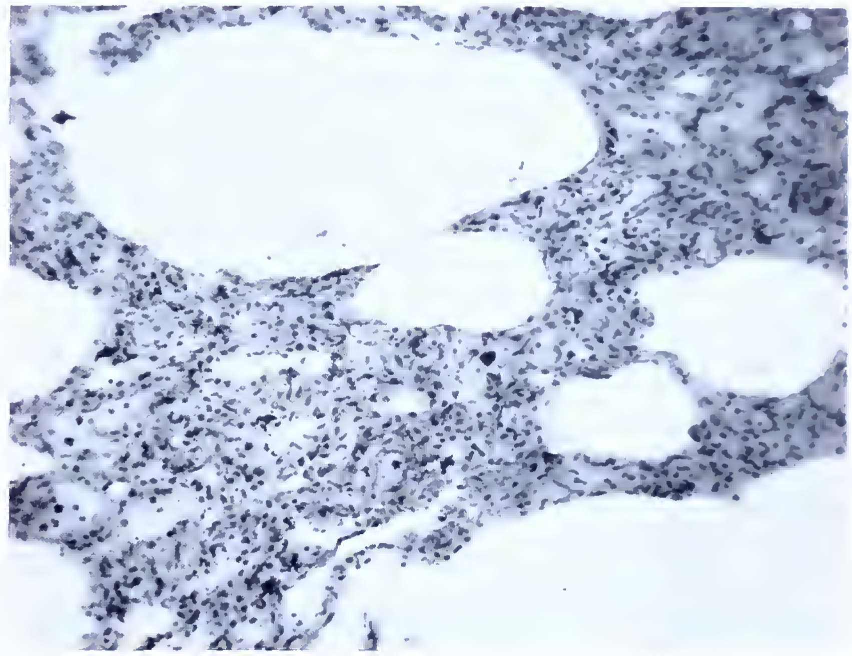
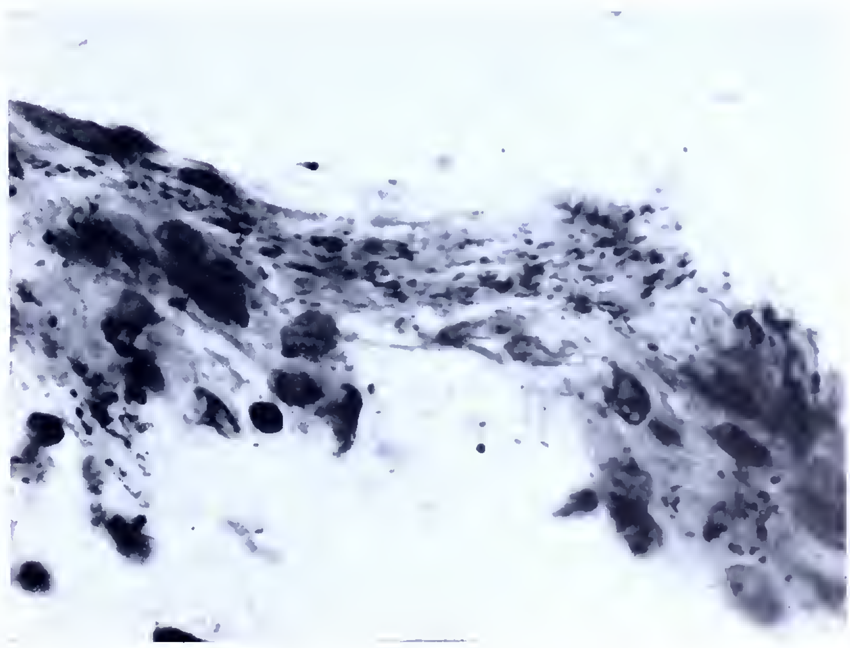


Figure 31.—*Case No. 3:* An alveolar wall containing black particles of dust scattered throughout the connective tissue framework and within cytoplasm of cells. X 900.



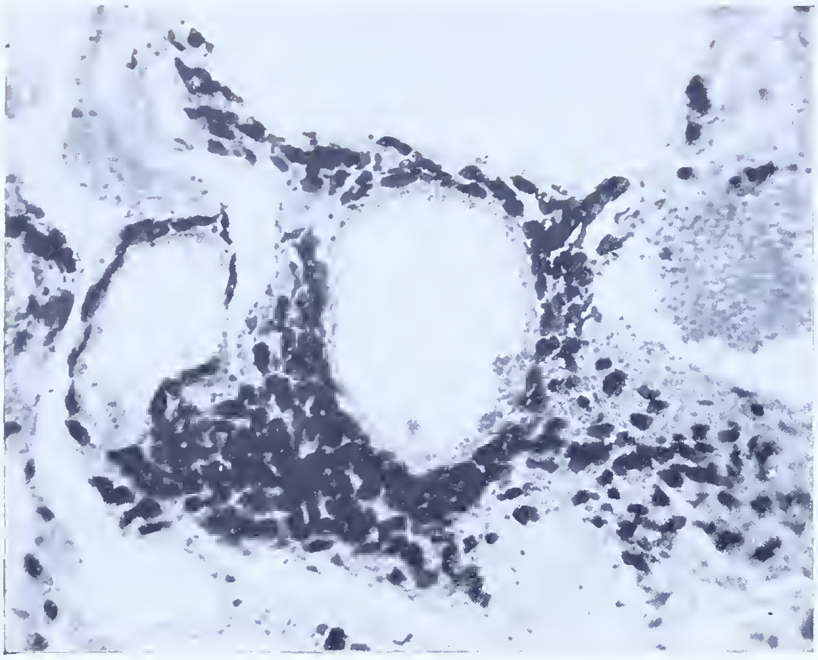


Figure 32.—*Case No. 3:* Masses of black pigment concentrated in the perivascular zone. There is little or no inflammatory reaction to the pigment. X150.

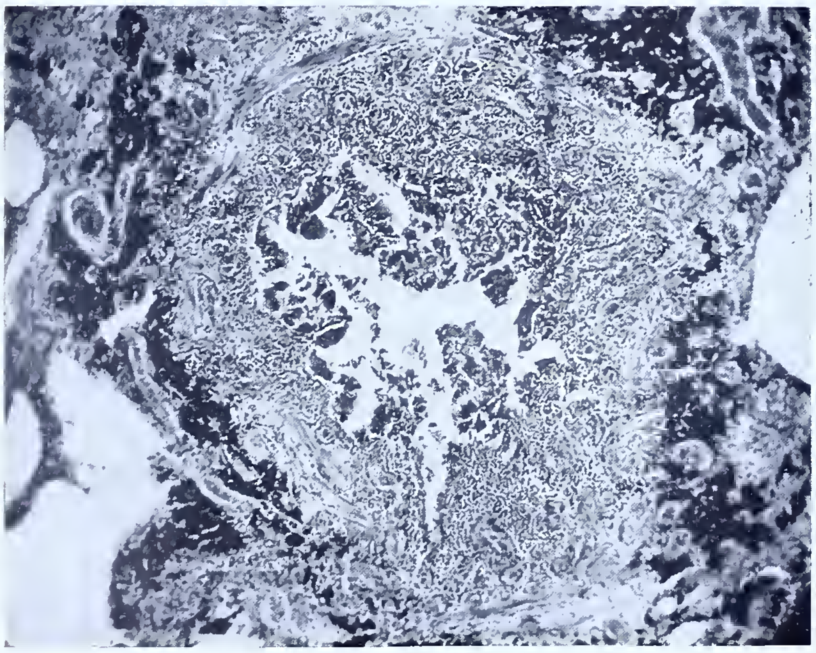


Figure 33.—*Case No. 3:* The lumen of the bronchiole contains masses of leukocytes and desquamated epithelial cells. The mucosa is ulcerated and the wall is infiltrated with leukocytes. The peribronchiolar tissue contains masses of black dust pigment. X50.

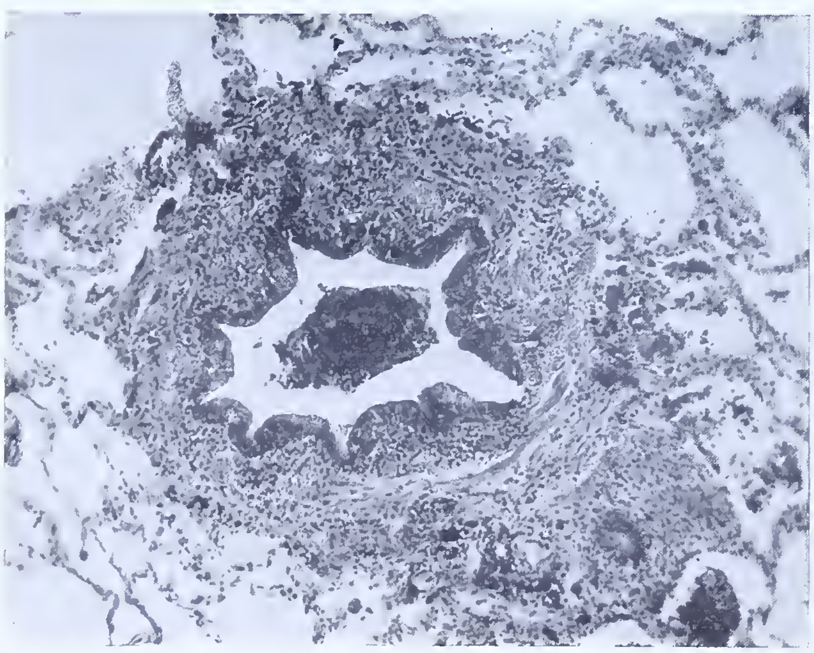


Figure 34.—*Case No. 15:* A bronchiole containing a plug of pus cells and showing leukocytic infiltration of its walls. X70.

Figure 35.—*Case No. 15:* A terminal bronchiole filled with a mass of pus cells. The surrounding tissue is infiltrated with leukocytes. Note the masses of black pigment in the area. X70.

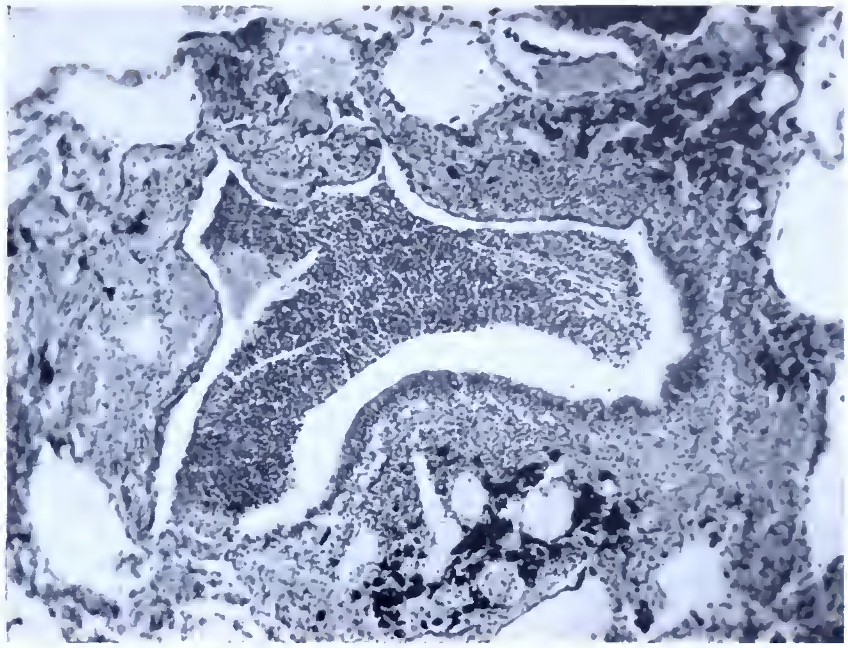


Figure 36.—*Case No. 15:* A focal area in which masses of leukocytes fill the alveoli of the lung. X150.

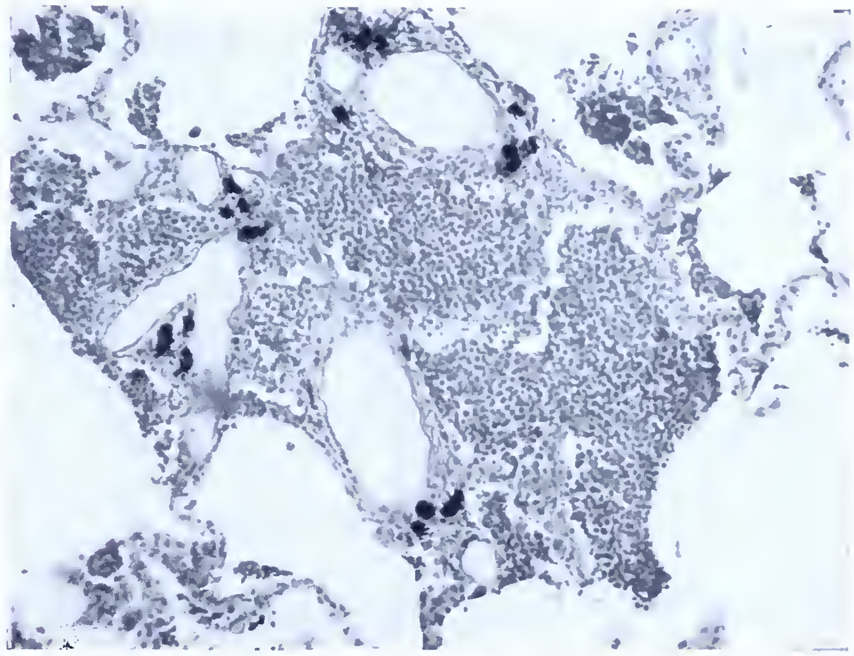
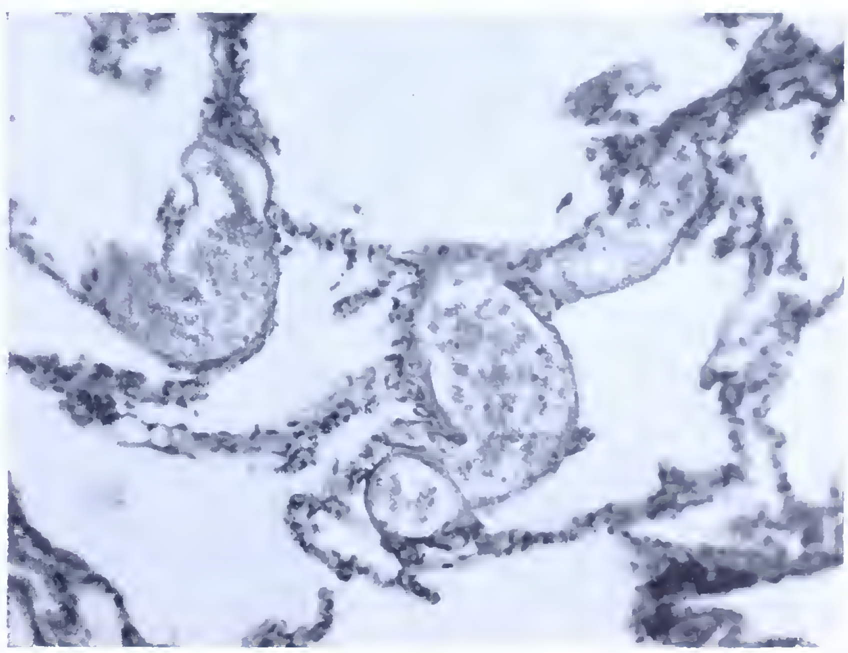


Figure 37.—*Case No. 15:* Dilatation of capillaries in some of the alveolar walls. The latter are thin, and without significant inflammation. The air spaces are irregular and distorted. X150.



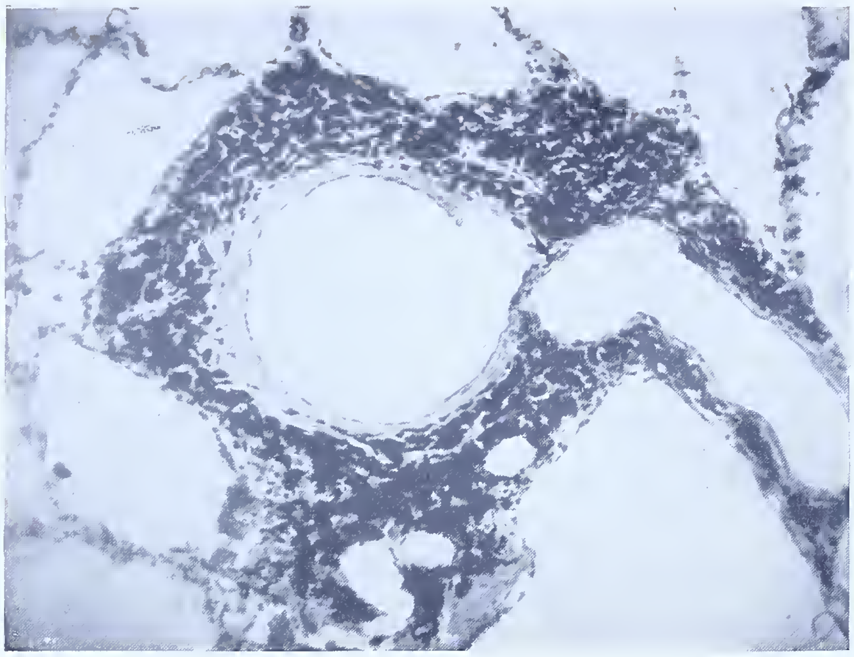


Figure 38.—*Case No. 15:* Perivascular concentration of masses of black dust without significant inflammatory reaction. X150.

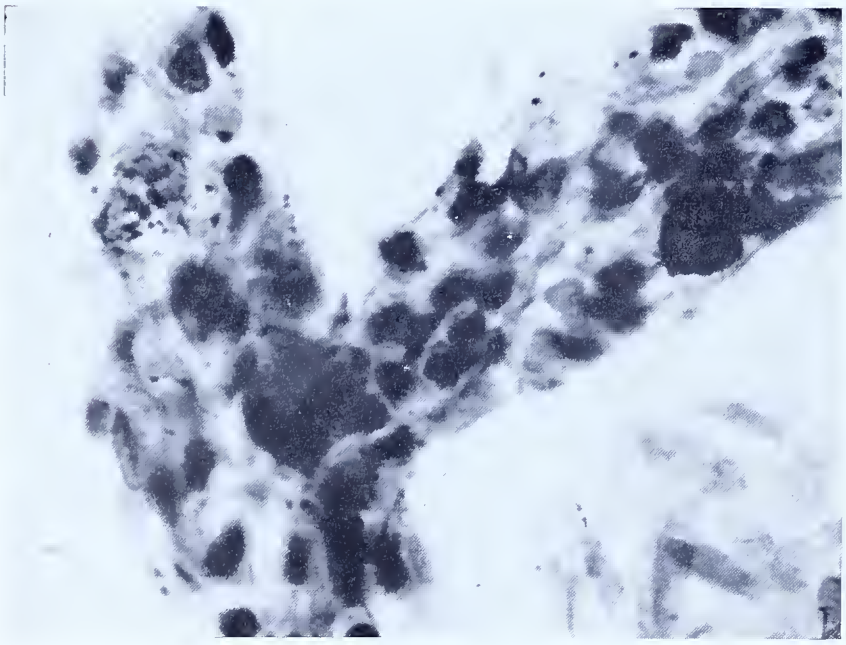


Figure 39.—*Case No. 15:* Particles of black dust lying free or within cells of the alveolar wall. X900.

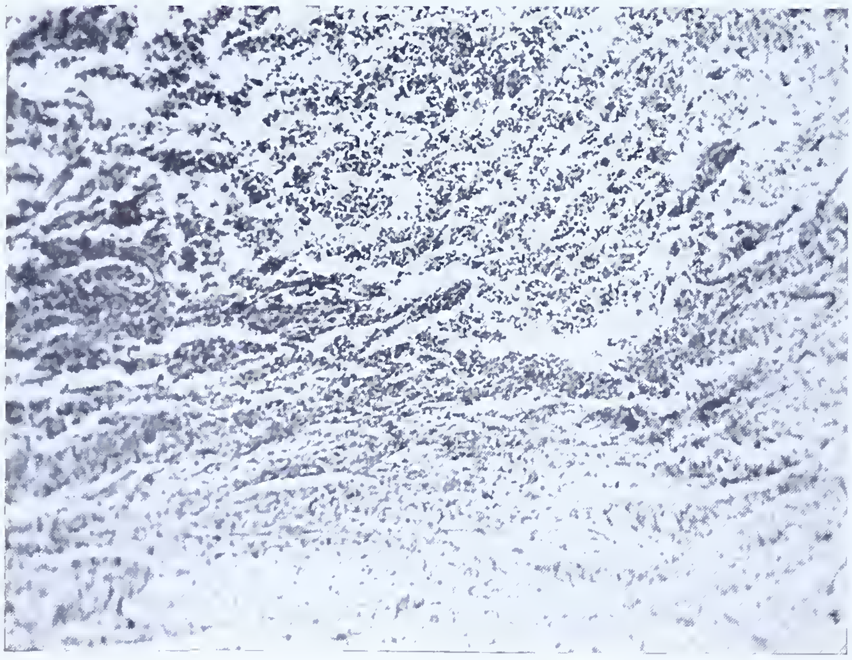


Figure 40.—*Case A–29 (hospitalized persons):* The section through a pulmonary abscess exhibiting the focal collection of pus cells surrounded by a zone containing strands of fibrin. X70.

Figure 41.—*Case A–29 (hospitalized persons):* The alveolar spaces contain masses of leukocytes with slight infiltration of the alveolar walls. X120.

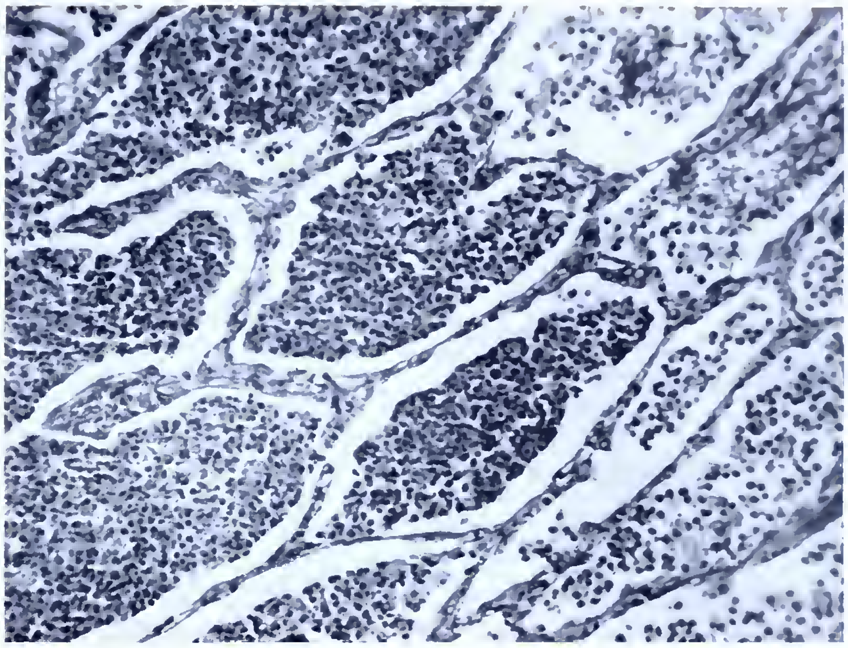


Figure 42.—*Case A–29 (hospitalized persons):* Fibrin plugs obliterating the alveolar spaces. The irregular, dark, fibrinous structures are retracted from the thin and less distinct alveolar walls. X120.

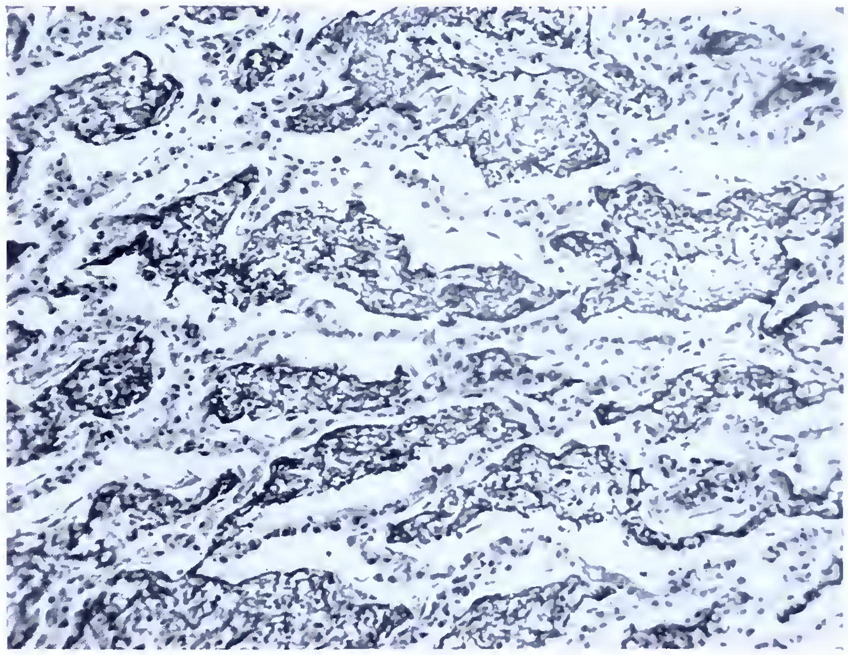
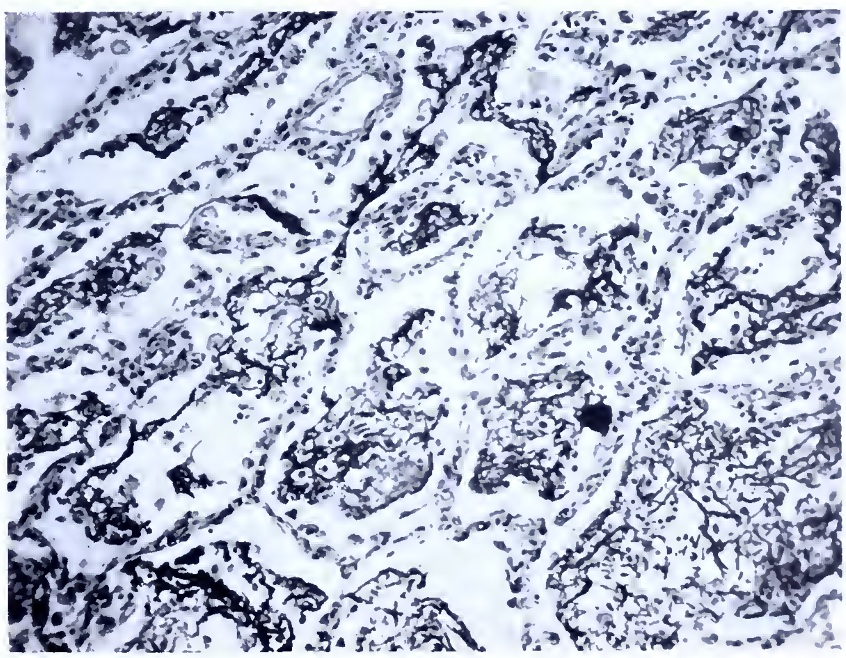


Figure 43.—*Case A–29 (hospitalized persons):* Alveolar walls thickened by a chronic type of inflammation consisting of scattered mononuclear cells and deposition of fibrous tissue strands. The apparent lining of the alveoli is composed of dilated capillaries filled with erythrocytes. Few such cells, together with an occasional dust-filled macrophage, lie free in the alveolar space. X120.



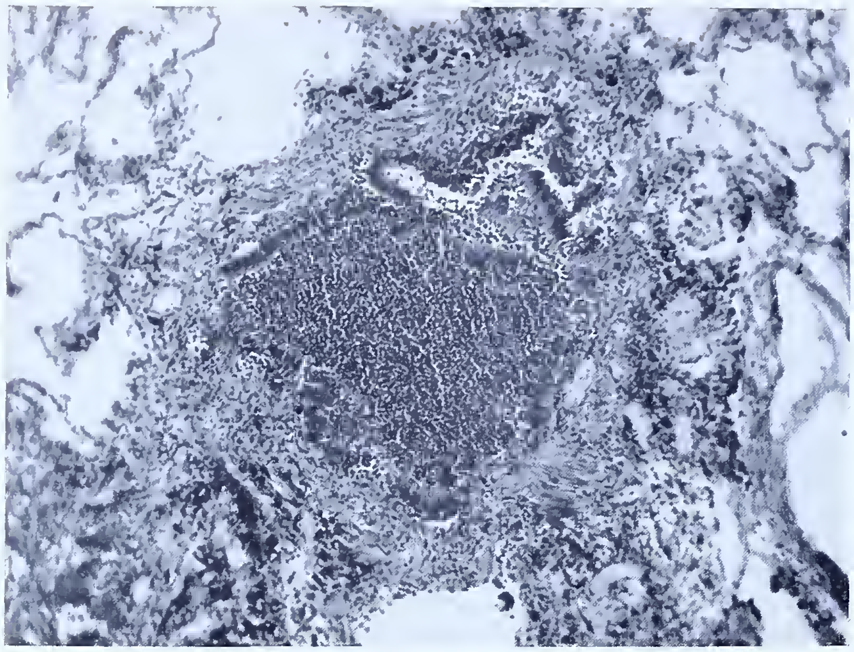


Figure 44.—*Case P:* A bronchiole occluded by leukocytes. The mucosa is partially detached and exhibits focal ulceration. Leukocytes infiltrate the wall and adjacent alveolar walls and spaces. X70.

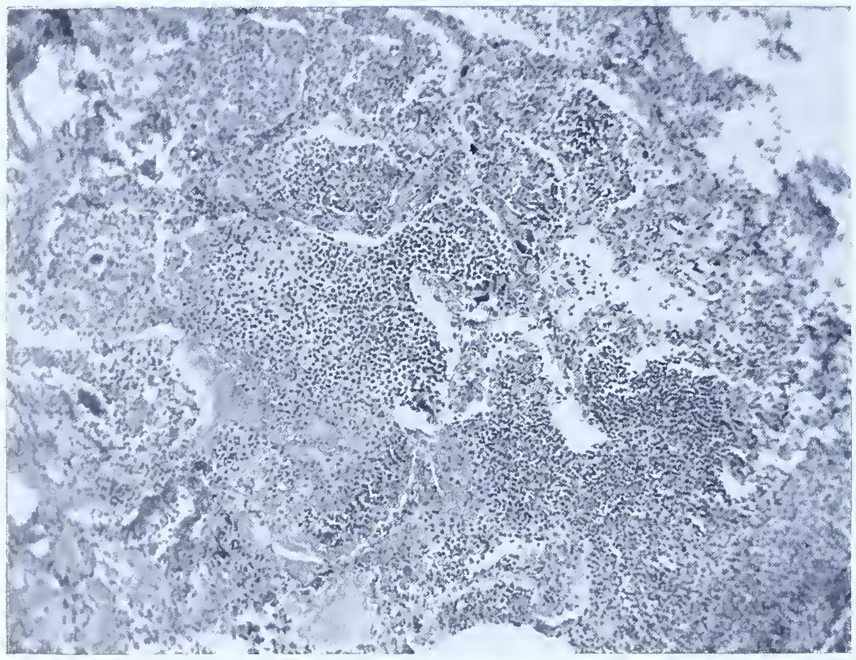


Figure 45.—*Case P:* Focal area of pus cells which fill alveolar spaces and infiltrate their walls. X70.

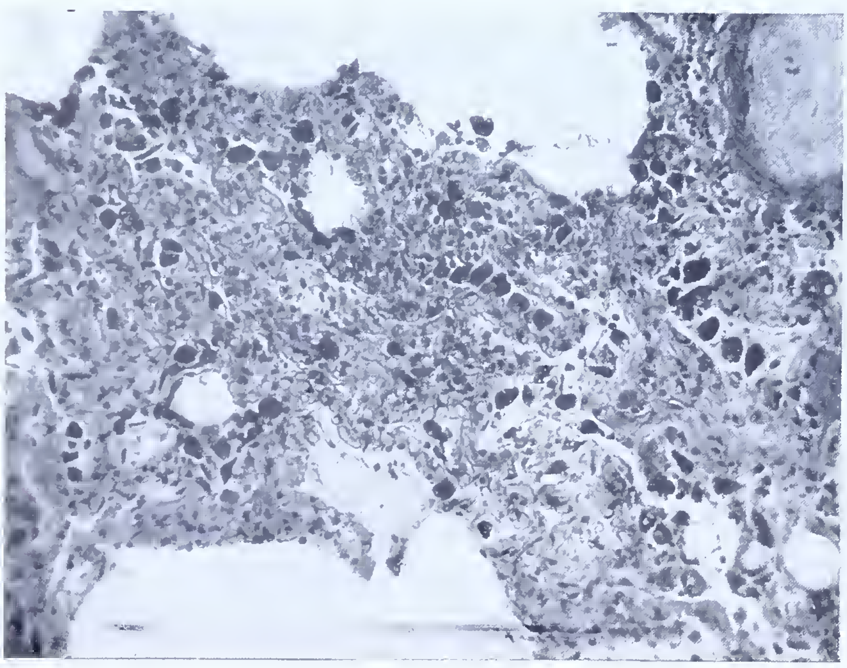


Figure 46.—*Case P:* An alveolar wall thickened by a proliferative type of inflammatory response. Dust laden macrophages are scattered throughout. X150.

Figure 47.—*Case P:* Focal proliferative types of reaction which obliterates the pulmonary architecture. X70.

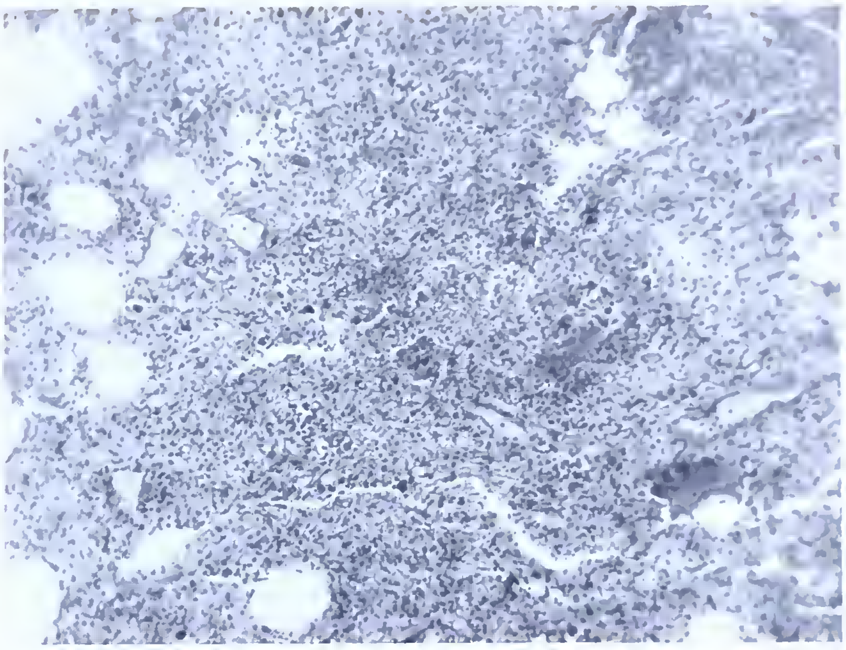


Figure 48.—*Case P:* Particles of black dust lying free or in macrophages within the framework of the alveolar walls. X900.

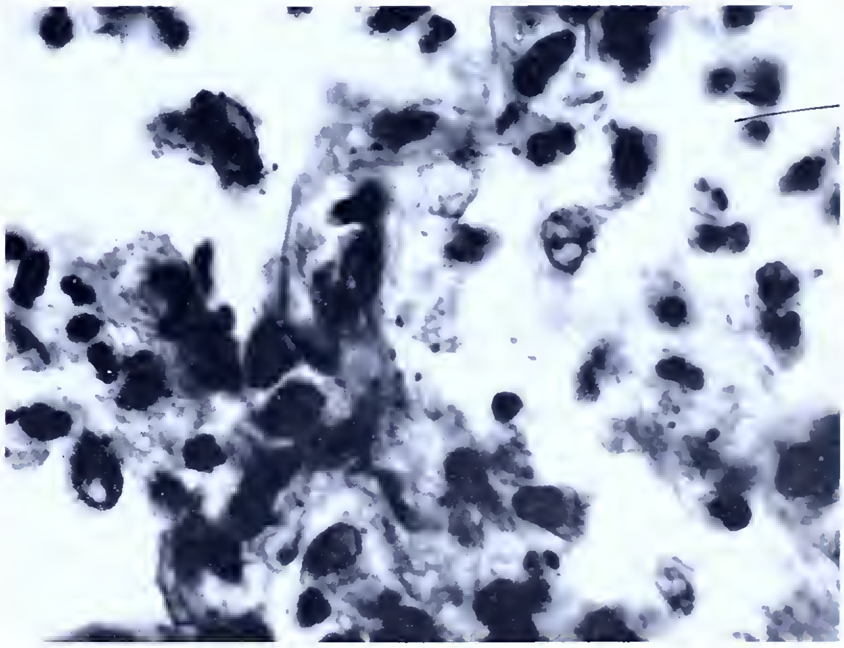


Figure 49.—*Case P:* Scattered masses of black dust concentrated in a tracheobronchial lymph node with widely dilated lymph and vascular channels. In the upper half of the section, there is a mild proliferative type of inflammatory reaction to the dust. X70.

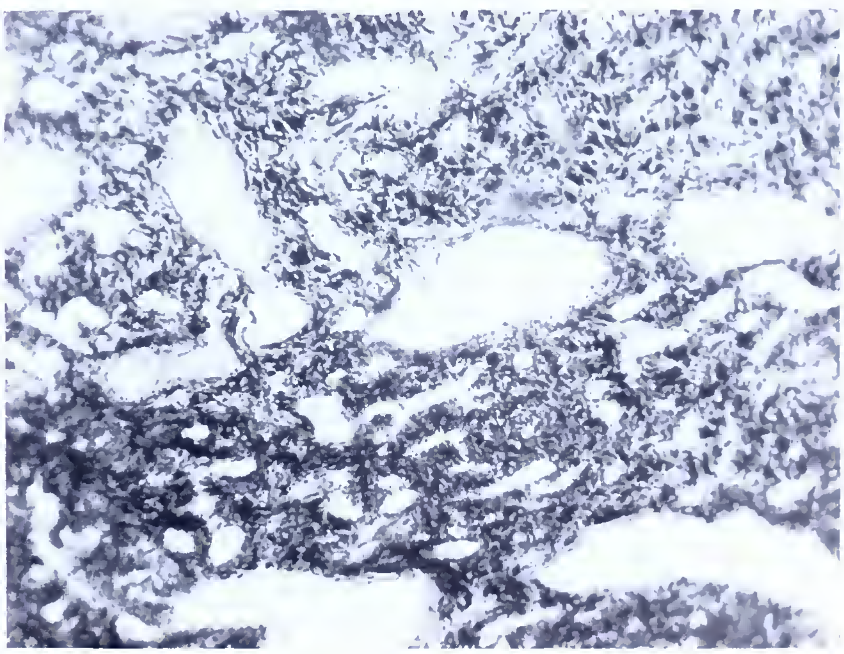


Figure 23.—Map showing the residences of 18 fatal cases in Donora area. The lowermost identifying mark is a distance of $1\frac{1}{2}$ miles from the actual location, in the indicated direction.

The findings follow:

Material	Found in trace amounts	Found in more than trace amounts
Bone	Iron.	Calcium, magnesium, silica, copper, boron, phosphorus.
Lung	Tin, zinc, lead, cadmium.	Magnesium, sodium, iron, aluminum, silica, calcium, copper, phosphorus.

Case A–30, age 63, male, white, policeman, widower, from Donora, was hospitalized on day No. 3.

On admission he complained of shortness of breath which began 5 days before, and a chronic productive cough of a few days' duration. The cough was productive of a blackish sputum. He also complained of pain in his left chest which radiated to the back. In giving his history, he indicated that he had such coughs every winter, during which he brought up a small amount of sputum, and also that he had dyspnoea during those times. He had no other complaints except that he mentioned that he knew he had had hypertension since 5 months before. He had noticed dyspnoea on exertion for some months. The rest of his history was negative.

On physical examination he was found to be normal throughout except for the following: The chest showed vesicular breathing, with fine crepitant rales present in the upper lobe on both sides. There were moist rales at the bases. Blood pressure was 165/105 and the apex beat was 102, with the pulse rate 86. There was marked pulse deficit and the heart rhythm was totally irregular. No heart murmurs were observed and the heart was apparently not enlarged. There was some swelling of the ankles and this was probably due to the varicose veins. No abnormalities were observed in the abdomen. There was no other sign of failure. Temperature and respirations on admission were within normal limits and remained so throughout his hospital stay.

The laboratory examinations indicated the following: Urine was normal except for a heavy trace of albumin and an occasional hyaline cast. The blood showed 95 percent haemoglobin, red blood cell count was 4,910,000, white blood cell count was 9,300, with a differential count of 67 percent neutrophils, 2 percent eosinophils, 29 percent lymphocytes, and 2 percent monocytes. The nonprotein nitrogen was 34 mg. percent. Sugar was 86 mg. percent. The sedimentation rate at the end of 1 hour was 12 mm. Kahn test was negative.

When the visiting physician saw the patient the next day he found that there was no indication for digitalis since there was no evidence of congestive heart failure. His blood pressure at this time was 170/100.

The electrocardiogram taken on the third hospital day showed auricular fibrillation and some evidence of right-sided preponderance.

The X-ray was negative insofar as the parenchyma of the lungs was concerned.

The therapy in this case consisted essentially of bed rest and, to a limited degree, antispasmodics. At no time were his symptoms of any grave severity. After a few days his dyspnoea became less severe and he was discharged after a two weeks stay in the hospital.

The discharge diagnosis in this case was arteriosclerotic and hypertensive heart disease, with auricular fibrillation.

Case A–31, 44, male, white, labor official, born in the United States, from Donora, was hospitalized on day No. 3 at about 4 p. m.

On admission he complained of cough and dyspnoea. The cough, which was productive of a black sputum, began three days before. Dyspnoea began as his cough progressed. His cough and dyspnoea were so severe that he could not sleep. He also had a headache and a pressing pain beneath the lower end of the sternum.

Review of the systems indicated that for the past several years he had always had cough, dyspnoea, and some precordial pain whenever smog conditions occurred. However, the present attack was the worst that he ever had. He had never had productive cough with his attacks except on this occasion.

Examination on admission showed that his respirations were rapid and shallow with some moist and dry crepitant rales present throughout the chest. There were no asthmatic rales noted, and breathing was normal. His blood pressure was 110/76. His temperature, pulse, and respirations were recorded as normal. The rest of the examination was negative, and a diagnosis of chronic bronchitis and asthma was made.

The laboratory tests were as follows: Urine was negative except for a trace of albumin. The blood showed 80 percent haemoglobin. The red blood cell count was 4,050,000, the white blood cell count was 8,100, the differential count was 66 percent neutrophils, 1 percent eosinophils, 30 percent lymphocytes, and 3 percent monocytes. The sputum was negative, both in direct examination and in culture.

The X-ray was essentially negative with reference to the parenchyma of the lung.

Four hours after admission the temperature rose to 100.6° F. and thereafter ran between 98° F. and 99.6° F., while he was hospitalized. His pulse was in proportion to his temperature, and his respirations were within normal limits.

He apparently was relieved of his symptoms after 2 or 3 days in the hospital. The treatment in this case consisted of penicillin, adrenalin as an antispasmodic, sedatives, expectorants, and bed rest.

He was discharged on the sixth hospital day with the diagnosis of acute upper respiratory irritation ("chemicals in the air") with the complicating diagnosis of bronchial asthma.

Case A–32, age 65, female, white, single, housekeeper, resident of Donora for 45 years, was hospitalized on day No. 3 at about 8 p. m.

She was said to have oedema of the ankle for several years probably related to varicose veins. The heart was said to "skip a beat occasionally." Three months before, she had noticed swelling of her ankles and shortness of breath. She was given medication for this which she had not taken continually. Six days before admission she contracted a cold and began to experience difficulty in breathing associated with a productive cough and cyanosis. Her physician gave her some medicine and finally decided that she should be hospitalized.

Review of the systems was essentially negative. She had the menopause 20 years before.

On physical examination she appeared slightly cyanotic and slightly dyspnoeic when she was coughing. She was noted to cough in paroxysms. The lungs showed numerous coarse moist inspiratory rales over both posterior lung fields. Her heart showed regular sinus rhythm. The sounds were of good quality and she had an occasional extrasystole. There was a soft blowing systolic murmur at the apex. The arteries were found sclerotic. Blood pressure was 126/84. The temperature was 99.4° F., pulse 80, and respirations 36. The rest of the physical examination was negative.

The urine examinations on two occasions were essentially negative, showing only a trace of albumin and an occasional hyaline cast. Blood studies revealed 80 percent haemoglobin, 4,120,000 red blood cells, 8,600 white blood cells, with a differential of 64 percent neutrophils, 2 percent eosinophils, 31 percent lymphocytes, and 3 percent monocytes. The nonprotein nitrogen was 36 mg. percent and the sugar was 92 mg. percent. Kahn test was negative. The sputum examination was essentially negative.

X-ray of the chest taken on the fourth hospital day showed no evidence of any pathological conditions of the parenchyma.

The electrocardiogram taken on November 1 showed evidences of myocardial damage. This was interpreted from the low voltage generally observed in all leads, and the inversion of the QRS in lead 3 and upright in lead 1. There was normal sinus rhythm. The auriculoventricular conduction time was normal.

Her vital capacity was noted to be 44 percent of normal and the venous pressure by the direct method was 12 cm. of water. Circulation time was 11 seconds, arm to tongue test by the decholin method.

Her temperature, pulse, and respiration remained essentially normal throughout her 7-day stay in the hospital.

Treatment in this case consisted of penicillin and antispasmodics.

She felt a great deal improved on November 2, with fewer rales being noted. The rales kept on getting less all the time until her discharge on November 5, 1948, when she was referred back to her physician.

Her discharge diagnosis was "possibly pneumonitis on a chemical basis." Earlier it was recorded that it might be a virus pneumonitis.

FATALITIES

Based on the 4-year average death rate for Donora Borough alone (1945–48), which appears in another section of this report, the expected number of deaths for the borough during any 7-day period is slightly less than two. During and after the October 1948 smog, for a period of 7 days, there were 12 deaths of Donora Borough residents which was six times the expected number. Because of the gross inadequacy of clinical data, it was a difficult matter in any individual instance to decide whether or not death was caused, or even hastened, by the smog. Although the number was small, from the point of view of statistical analysis, a careful study was made of the data available for the persons who died.

It was expected that such a study would serve a threefold purpose, namely: (1) To further our knowledge of the clinical disease entity due to the smog; (2) to obtain data on the pathological changes which might be found in the organs; and (3) to study the tissues and organs for chemical substances which might be of significance as etiologic agents.

Methods of Study

Available clinical data for each case were obtained by conference with local physicians, relatives of the deceased, hospital officials, and all others who might have had knowledge about the patient when he was alive. Record was also made of the place of burial, since such information would be useful if it was wished to disinter the body for autopsy.

After a study of all available data, each case record was examined to evaluate the degree to which death was probably due to, or hastened by, the smog. In the entire area considered, there were 20 persons who died during or shortly after the smog period. Of this number, there were 18 for whom there were sufficient data to warrant analysis. For the other two, cases No. 19 and No. 20, the only facts available to us were those contained in the death certificates and these were not considered sufficiently informative to permit an evaluation of all contributory causes of death. Hereafter, therefore, when reference is made to the fatal cases, only the first 18 will be considered unless otherwise indicated.

From the 18 fatal cases, a group was chosen for which it was considered that an autopsy would be useful. As would be expected, obtaining permission for autopsy of the persons who had died and had been buried 5 months previously, was not an easy matter. In spite of cooperation from Borough officials and local religious leaders, permission for autopsy was obtained in only two instances. These two autopsies, as well as one done shortly after death on authorization of the county coroner, were the only ones performed on the bodies of persons who died during, or shortly after the smog. A fourth autopsy was performed on the body of one person (Case A–29 of the "hospitalized" persons) who died 2 months after the smog, and a fifth in the instance of a man who died 8 months after the episode. These cases are considered separately in the latter part of this section.

Descriptions of all the fatal cases, including cases No. 19 and No. 20, appear immediately following this section. Case A–29 was presented in detail in the section referring to hospitalized persons. The description of the last case autopsied appears as case P after case No. 20.

General Findings

The ages of the 18 persons who died ranged from 52 to 84 years with a median of 65 and an arithmetic mean of 65 years. This is in conformity with the findings for the nonfatal illness where the highest incidence of severe illness, allegedly due to the smog, occurred among persons in the older age groups.

Five of the persons were women, and 13 were men. It was found that the women were younger, on the average, than the men. Thus, the median age of the women was 58 years, and the arithmetic mean 60 years. Further study of the data, however, revealed that men were more likely to have been fatally affected than women only in the age group 65 years and over; but, that in the age group 50–64 years, inclusive, the rates for men and women were the same.

Five of the fatalities occurred among nonwhite persons giving a rate of 4.2 per 1,000 of nonwhite population. The rate for the white population was 1.0 per 1,000. The rate for the entire population studied was 1.3 per 1,000.

Study of the principal past occupation showed that the five women were all housewives, and, that of the men, four had worked at various operations in the local steel plant, six had been coal miners, one a barber, one a railroad worker, and one had had no regular employment. Except that the occupation of coal-mining may have contributed to chronic respiratory system disease, no significance is attributable to the factor of principal past employment.

The places of residence of the persons who died are shown in figure 23. When rates were calculated for the deaths in the 12 residence districts of the area studied, as shown in table 19, it was found that in Donora (including Carroll Township) there were no significant differences among the districts, whereas Webster residence districts showed a distinct increase over those in Donora. The rate per 1,000 population for Webster was 6.6 and for Donora (including Carroll Township) 0.9 per 1,000. As determined by statistical study,

TABLE 19.—*Death rate per 1,000 persons in residence districts of Donora area; rates based on 18 deaths, 17 occurring between 2 a. m. on day No. 3 and 12 p. m. of day No. 4, and 1 occurring on day No. 12*

Residence district	Death rate per 1,000 persons	Number of deaths	Number of persons [1]
Total, Donora area	1. 3	18	13, 839
Donora, and Carroll Township [2]	. 9	12	12, 927
12	1. 4	1	696
9	1. 3	3	2, 346
10	1. 1	5	4, 587
1	1. 1	1	945
11	1. 0	1	981
2	. 7	1	1, 482
3	0	0	1, 644
Webster [3]	6. 6	6	912
6	5. 6	2	357
4	2. 6	1	387

[1] See footnote 1, table 2.
[2] Includes 246 persons in other sections of Carroll Township.
[3] Includes 3 deaths, and 168 persons in other sections of Webster.

neither age nor previous state of health accounted for this difference. It is of interest to note that another section of the report shows that the incidence of illness, especially severe illness, was higher in Webster than in Donora.

Available data on duration of continuous residence of the 18 persons who died in the Donora area reveal that length of residence ranged from 6 to 52 years, with a median of 35.5 and an arithmetic mean of 33.3 years. For the age group of the population of the area which would most nearly correspond to the age group in which the fatalities occurred, that is, 50 years and older, it was found that the duration of continuous residence in the Donora area was 32.6 years as the median, 33.2 years as the arithmetic mean, and the range was from 5 to 55 years. This signified that duration of residence in the community was not a factor in the fatal cases.

The fatal illnesses began on S-day in 3 cases, on day No. 1 in 4 cases, on day No. 2 in 10 cases, and day No. 3 in 1 case. This, however, was corrected since all of the cases that allegedly began on S-day were relieved of symptoms on the next day, only to become ill again later, 1 on day No. 1, and 2 on day No. 2. Thus corrected, it was found that 5 became ill on day No. 1, 12 on day No. 2 and 1 on day No. 3. These data appear in figure 24. It is apparent that day No. 2 was the day on which the majority of the persons who died became sick, a fact which agrees with the pattern found for the large number of nonfatal cases studied.

Figures 24 and 25 show the periods of time of illness in actual day and hour for each of the 18 persons who died. Seventeen of the persons were ill for the hours extending from 9:00 p. m. of day No. 2 to 2:30 a. m. of day No. 3, a period of 5½ hours, which compares favorably with the period of highest frequency of the incidence of the illnesses during the smog.

The first person who died became ill at 4:00 a. m. of day No. 1, and the last one at 6:30 a. m. of day No. 3. It appears that by 8:30 p. m. of day No. 2, seventeen of the 18 persons had started their illnesses, and that none had died up to that time. Table 20 shows the incidence of the "sick hours" for the period from days Nos. 1 through 4. One person, No. 18, was ill for 10 days before he died on day No. 12.

TABLE 20.—*Cumulative number of person-hours of illness arising from 18 fatal cases*

Hour of specified day	Day No. 1	Day No. 2	Day No. 3	Day No. 4
1 a. m.	0	70	356	549
2 a. m.	0	75	373	552
3 a. m.	0	80	386	555
4 a. m.	1	86	399	558
5 a. m.	2	92	411	561
6 a. m.	4	99	422	563
7 a. m.	6	107	433	565
8 a. m.	9	116	444	567
9 a. m.	12	126	453	569
10 a. m.	15	137	462	571
11 a. m.	18	148	470	573
12 a. m.	21	159	478	575
1 p. m.	24	171	486	576
2 p. m.	27	183	494	577
3 p. m.	30	195	502	578
4 p. m.	33	208	509	579
5 p. m.	36	223	514	580
6 p. m.	39	239	519	581
7 p. m.	42	255	524	582
8 p. m.	45	271	529	583
9 p. m.	50	288	534	584
10 p. m.	55	305	539	585
11 p. m.	60	322	543	586
12 p. m.	65	339	546	587

The fatal issue occurred in 15 of the 18 cases considered on day No. 3, in 2 on day No. 4, and in 1 on November 8 (day No. 12). The first death occurred at 2:00 a. m. of day No. 3, and by 10:30 a. m. of that day, a period of 8½ hours, 10 persons had died.

The illness lasted from 5½ hours to a total of 10 days. Omitting from consideration case No. 18 which lasted 10 days, the length of the fatal illnesses ranged from 5.5 to 64.5 hours, with a median of 22.0 and an arithmetic mean of 32.0 hours. Figure 25 shows graphically the duration of the illnesses in ascending order. It will be observed in this figure that the cases appear to be equally divided into those of duration less than 24 hours and those of duration longer than 24 hours. This matter is considered further below.

An attempt was made to determine if any definite pattern existed for the fatalities in terms of their places of residence, related to the order of the time of onset of their illnesses, and also to the order of the time of death. When these were plotted on a map of the area it was found that no definite pattern appeared and that the distribution was probably a random one.

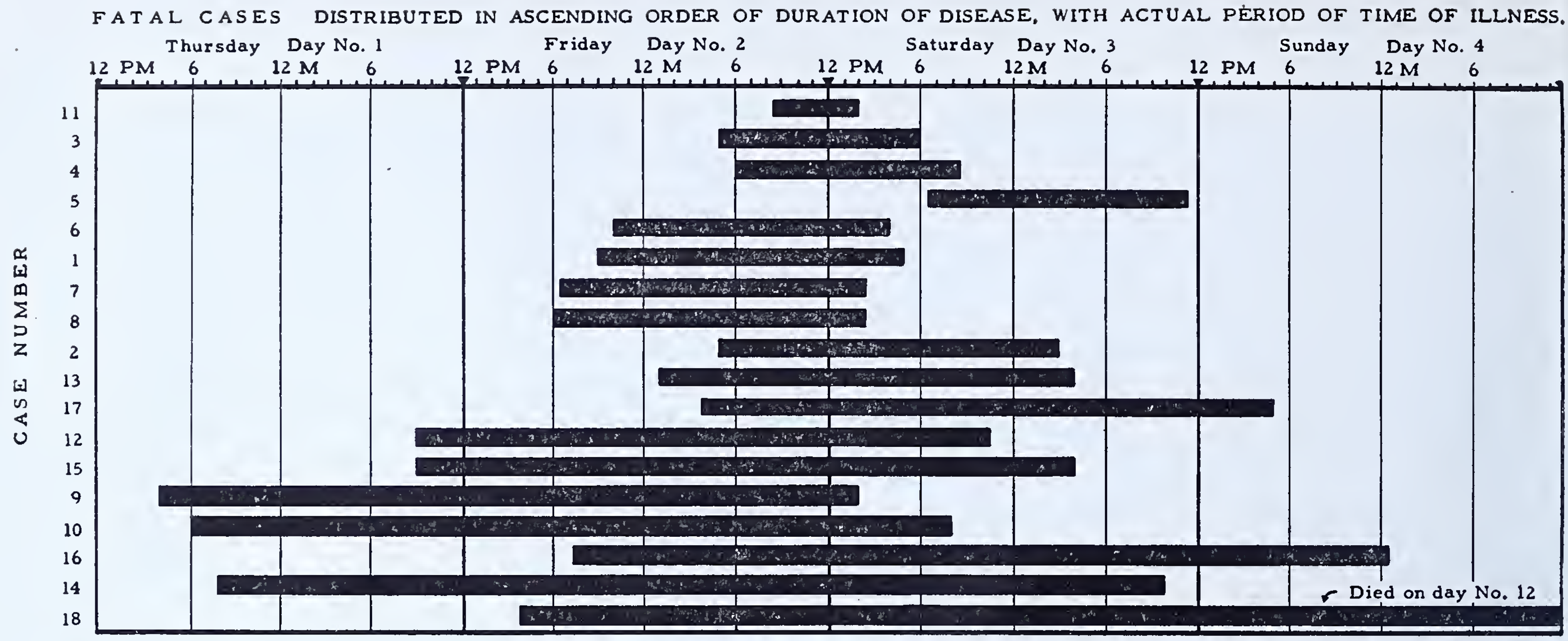
Table 21 presents the frequency of the prominent symptoms and signs of the fatal cases. It will be observed that dyspnoea occurred in 17 of the 18 cases, orthopnoea in 14, nonproductive cough in 8, chest discomfort in 4, abdominal distress in 3, headache in 2, and productive cough in 1. In addition, weakness was reported in 5 cases and cyanosis in 4. In only one instance, case No. 17, were no symptoms elicited referrable to the cardiorespiratory system.

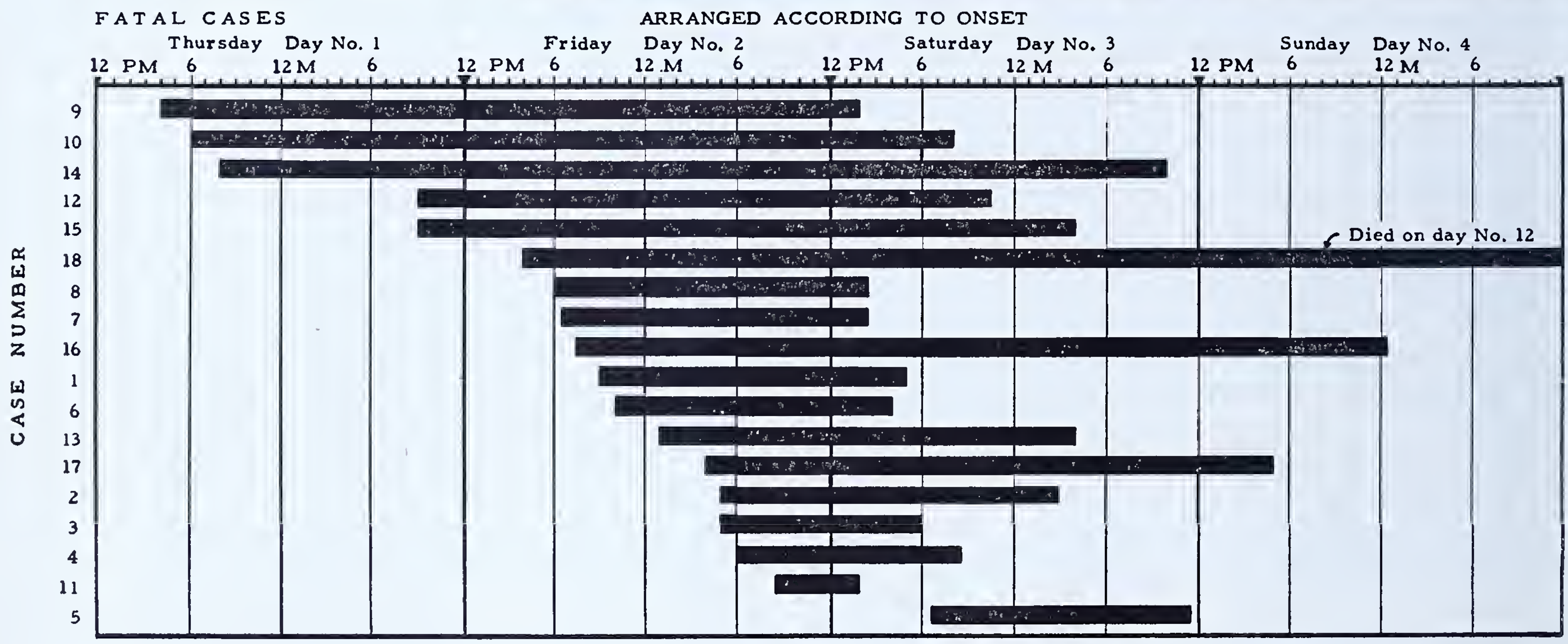
The same table lists the previous health status of the 18 cases. The outstanding facts from these data are that there were four persons whose past medical history gave no clue to their having had any chronic disease prior to the smog, and of the remaining 14 there were 12 who had evidence of chronically diseased cardiorespiratory systems. Thus, bronchial asthma alone was present in one case, heart disease alone in five, heart disease with bronchial asthma in two, heart disease with silicosis in one, "silicosis," based on history alone, in two, and pulmonary tuberculosis in one. Of the final two cases, one had hypertension and the other was suspected of having a gastric carcinoma.

For 15 cases for which there were adequate data to evolve a working diagnosis, the causes of death were chronic heart disease of varying etiology in 9, bronchial asthma in 1, chronic heart disease with bronchial asthma in 4, and pulmonary tuberculosis in 1. In the other three, causes of death although available, had but little supporting data in our opinion. It is of interest to note that of the three cases autopsied, chronic disease of the heart or lungs was found in all.

Duration of Fatal Illness

As was noted above, 9 cases (Nos. 1, 2, 3, 4, 5, 6, 7, 8, and 11) had a duration of less than 24 hours, and 9 (Nos. 9, 10, 12, 13, 14, 15, 16, 17, and 18) had a duration of over 24 hours. It appeared, therefore, that it might be useful to compare the 2 groups as to their various characteristics to find if any of these could have accounted for the difference in duration.





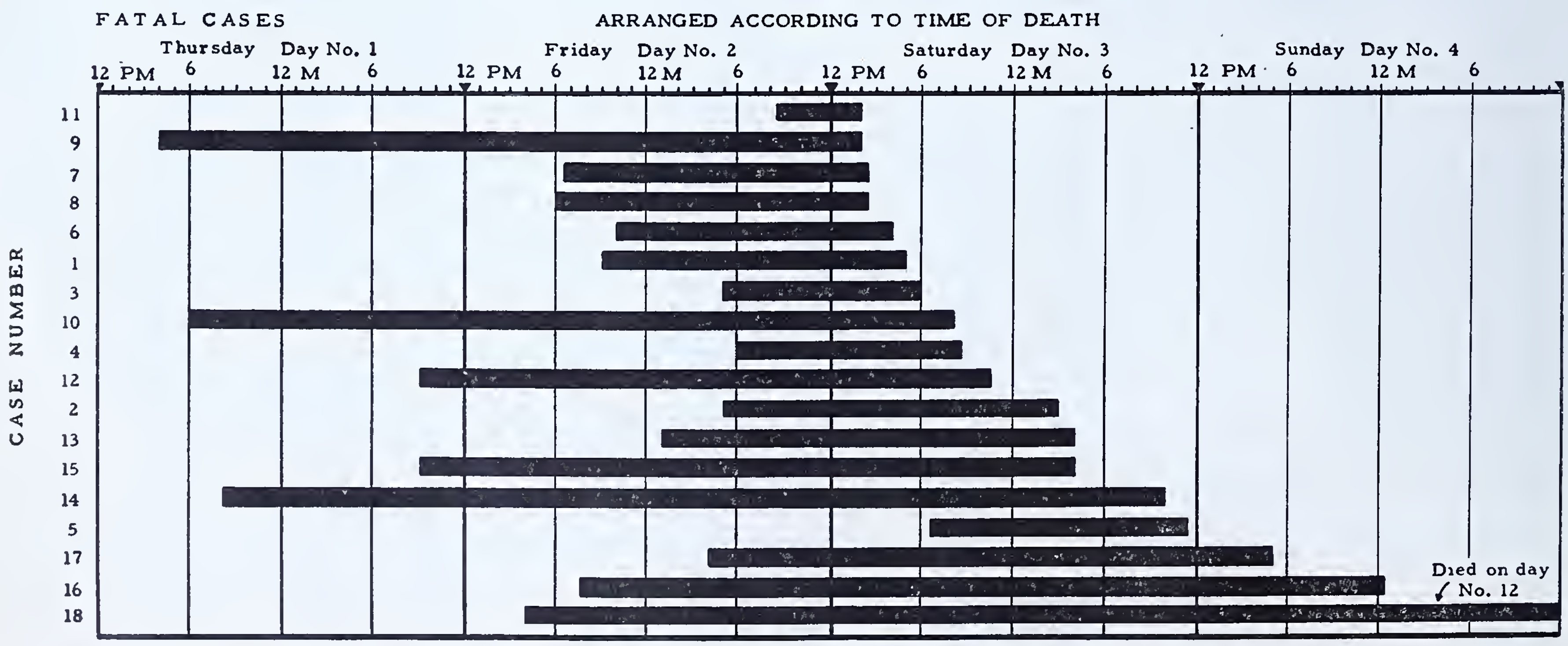


FIGURE 24.—*Chronology of 18 fatal cases. Cases are presented (a) in ascending order of duration of illness; (b) in order of onset of illness; and (c) in order of occurrence of death.*

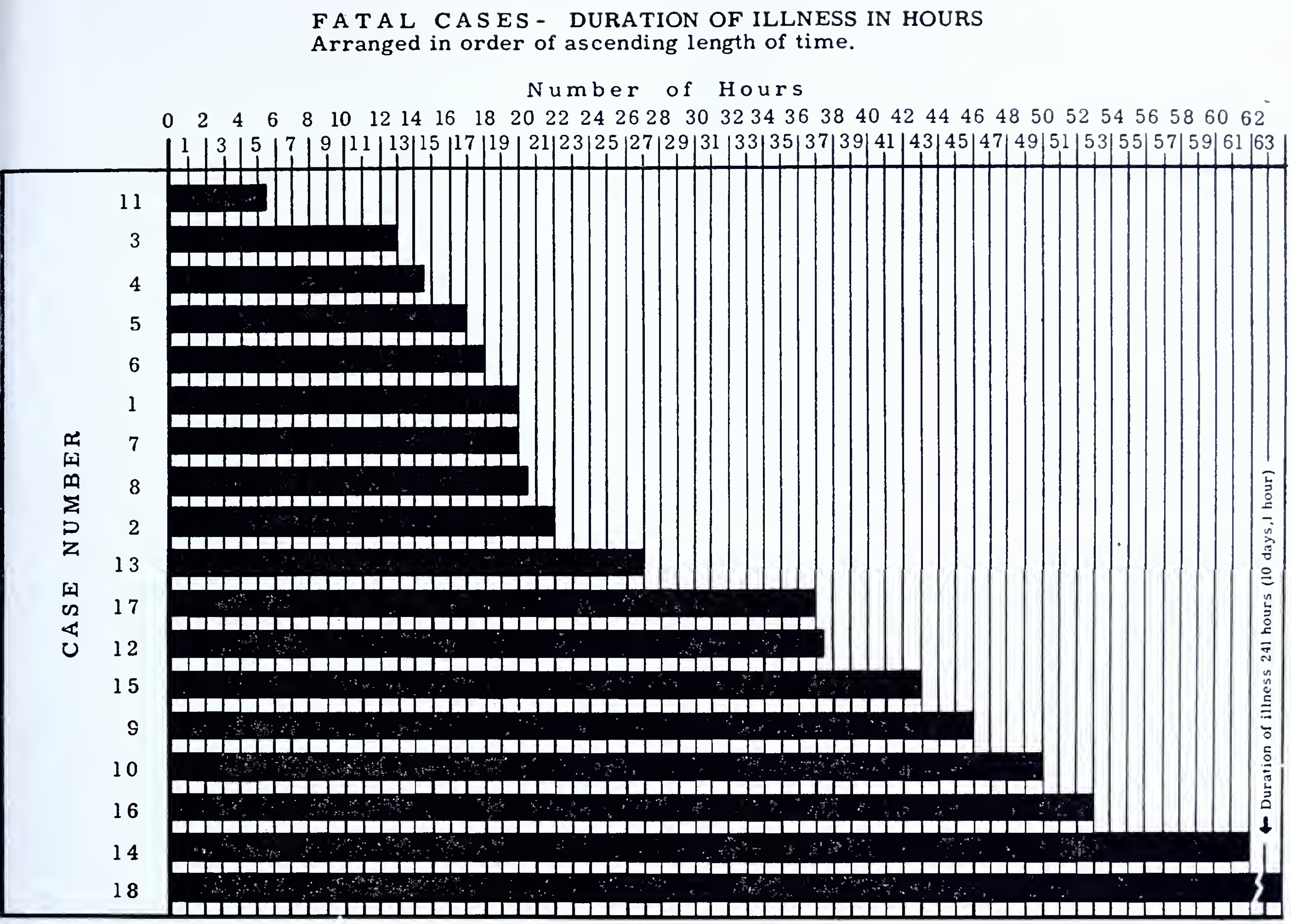


FIGURE 25.—*Duration of illness in 18 fatal cases.*

The ages of persons with fatal illness of less than 24 hours ranged from 52–84 years with a median of 64. The corresponding range of length of residence in the community was 10–52 years with a median of 30. For persons with fatal illness of more than 24 hours ages ranged from 55–81 years with a median of 66, and duration of local residence ranged from 6–65 years with a median of 42. It appears, therefore, that the two groups did not differ significantly in respect of these factors.

Table 21 shows various other characteristics which were examined. From this table it can be seen that the two groups did not differ significantly as to the following: Sex, race, place of residence, the first symptoms to have occurred, place of onset, the nature of the respiratory system symptoms, previous health status, degree of seriousness of previous health status (judged by the nature of the chronic disease present and the amount of disability created by it), and predominance of cardiac or respiratory disease as the preexisting disease. By this same procedure of testing it was observed that differences for the two groups did appear for the following: The time of the onset of the illness, "other symptoms" present, and whether or not medical attention was received. No opinion can be expressed of the coincidence of oxygen therapy received and of the occurrence of hospitalization, since there were exceedingly few cases where information was available for either of these characteristics.

Of the nine who were ill for more than 24 hours, it was observed that the "other symptoms" group occurred with greater frequency than among the others. This was accounted for chiefly by the symptom of retrosternal distress (four times). The significance of this is not apparent.

Eight of the nine of those who were ill for more than 24 hours had the services of a physician and the same eight received parenteral therapy of one type or another. Only four of the short-term illness group received the ministrations of a physician and three of them had parenteral medication. The nature of the medication was not available to us in all the cases, but appeared to be adrenalin or aminophyllin, or some other antispasmodic. There is no indication that early attention by a physician was a factor in prolonging life, since in most instances the medical attention came after 18–24 hours following the onset.

There is no reason apparent for the variation in duration of the fatal cases. Certain variables may possibly be significant, but data are not available to indicate more than a coincidental relationship.

TABLE 21.—*Frequency of various factors among persons with fatal illness of specified duration*

Factor	Number of persons with fatal illness of specified duration		
	Total	Less than 24 hours	More than 24 hours
Sex:			
Males	13	6	7
Females	5	3	2
Race:			
White	13	6	7
Nonwhite	5	3	2
Residence:			
Donora, and Carroll Township	12	5	7
Webster	6	4	2
Previous health status:			
Negative	4	2	2
Heart disease	5	3	2
Bronchial asthma	2	2	0
Silicosis	2	1	1
Heart disease and bronchial asthma	1	0	1
Pulmonary tuberculosis	1	0	1
Hypertension	1	0	1
Heart disease and silicosis	1	0	1
Cancer of stomach	1	1	0
Time of onset of illness:			
Day No. 1:			
12 p. m. to 6 a. m	2	0	2
6 a. m. to 12 m	1	0	1
12 m to 6 p. m	0	0	0
6 p. m. to 12 p. m	2	0	2
Day No. 2:			
12 p. m. to 6 a. m	2	1	1
6 a. m. to 12 m	4	3	1
12 m. to 6 p. m	5	3	2
6 p. m. to 12 p. m	1	1	0
Day No. 3:			
12 p. m. to 6 a. m	0	0	0
6 a. m. to 12 m	1	1	0
Place of onset of illness:			
Home	14	8	6
Place of work	2	1	1
Street	2	0	2
First symptoms:			
Dyspnoea	16	9	7
Orthopnoea	3	2	1
Nonproductive cough	6	4	2
Retrosternal distress	4	0	4
Abdominal symptoms	2	1	1
Productive cough	1	1	0
Headache	2	0	2
Respiratory symptoms:			
Dyspnoea	17	9	8
Orthopnoea	14	8	6
Nonproductive cough	8	5	3
Productive cough	1	1	0
Other symptoms:			
None	5	4	1
Retrosternal distress	4	0	4
Abdominal symptoms	3	1	2
Headache	2	0	2
Time of death: [1]			
Day No. 3:			
12 p. m. to 6 a. m	7	6	1
6 a. m. to 12 m	3	1	2
12 m to 6 p. m	3	1	2
6 p. m. to 12 p. m	2	1	1
Day No. 4:			
12 p. m. to 6 a. m	1	0	1
6 a. m. to 12 m	0	0	0
12 m. to 6 p. m	1	0	1
6 p. m. to 12 p. m	0	0	0

[1] 1 person died on day No. 12.

Autopsy Findings [10]

Tissues and organs of three persons who died during the smog were available for study (cases Nos. 2, 3, and 15). In addition, there were two persons who had been ill during the smog, and who died some time later, one 2 months after, and one 8 months after the incident. The first three are considered as a group, and following a comparison among them, the group will be compared with those who died later. Thus, the first three cases may be viewed as representing the acute phase of the incident in contrast with the other two which represent the chronic or delayed phase. The individual autopsy findings are presented following the case descriptions to which they apply.

[10] By Arthur J. Vorwald.

The pulmonary tissue from the three persons who died on day No. 3 exhibits acute changes identified as capillary dilatation, haemorrhage, oedema, purulent bronchitis and bronchiolitis. These changes are present in varying degrees of severity, capillary dilatation being most prominent in case No. 15 and less so in case No. 2. Focal haemorrhage is present in case No. 3 whereas focal oedema is conspicuous in case No. 2. Both are minimal in case No. 15. The inconsistency of these changes is difficult to interpret. They may have occurred as a direct result of the incident. However, if the same etiological agent were involved one would expect those changes to be somewhat more comparable in severity. Again, similar findings are not uncommon as agonal or post-mortem changes in many cases coming to autopsy. Therefore, they cannot be attributed unequivocally to the influence of the smog.

Acute inflammation characterized by the purulent bronchitis and bronchiolitis with leukocytic infiltration of the walls of these passages, and the formation of lobular pneumonia is pronounced in cases No. 3 and No. 15, but they are not at all prominent in case No. 2. With respect to these acute inflammatory processes, it is evident that they occurred prior to death. Therefore, there is no possibility of their being the result of post-mortem change. However, their relationship to the incident is questionable for two reasons, namely: (1) They are common findings in general autopsy material, and (2) they are present also in the other two cases, A–29 and P, which died months after the incident, by which time any acute changes having direct relation to the smog should have resolved or become chronic.

The chronic changes present in the lungs of the three cases in the acute phase of the incident may be considered from the viewpoint of the vascular bed, the alveolar walls and spaces, the major air passages and finally the pneumoconiosis.

With reference to the vascular bed, only case No. 15, shows an appreciable involvement consisting of mural thickening often accompanied by detachment of the wall from the surrounding loose connective tissue. The etiology of this change is obscure unless it has reference to the general cardiovascular pathological conditions discovered. It is not a conspicuous feature in the remaining two cases irrespective of the emphysema present in both, the diffuse parenchymal fibrosis, and the chronic bronchial and bronchiolar changes seen in one.

The alveolar walls are greatly thickened in only one, case No. 3. Here it is diffuse in type often causing obliteration of the pulmonary architecture. The proliferative nature of the thickening gives evidence of chronicity which could not have occurred within a period of 3 days. Therefore, it

is reasonable to conclude that this change antedated the smog.

The pneumoconiosis, for the most part, is relatively benign in type. The particles of dust occur in masses in the connective tissue sheaths about the vascular trunks, the interlobular septa and as focal collections in the alveolar walls. In addition, the dust is dispersed as individual particles within phagocytic cells or the connective tissue framework of the alveolar walls. In general, the tissue reaction to the dust is no more severe than might be expected to any dust classified as inert. The only exceptions to this general observation are the mild proliferative type of inflammatory reaction to the dust present in case No. 3 and the subpleural anthracosilicotic nodule of pigmented fibrous tissue observed in case No. 2. This nodule is typical of the reaction to free silica modified by anthracotic material. Even in these two cases, the majority of localizations of dust reveal no evidence of activity.

The impression that the bulk of the dust inhaled was inert is corroborated by study of the tracheobronchial lymph nodes. If the dust were even mildly active, one would expect to find evidence of activity in the nodes containing large quantities of dust drained from the lung. This, however, is not the case. Although the nodes are heavily laden with black dust, nevertheless, they fail to show a significant degree of inflammation or fibrosis.

The cases A–29 and P, which died several months after the incident, also exhibit acute and chronic pulmonary changes. With few exceptions, they are similar to those cited in the first group of cases which died during the smog. The exceptions have reference primarily to the extent rather than to the basic character of the involvement. They include the abscess formation with advanced lobular pneumonia and with purulent bronchitis and bronchiolitis, oedema and mild haemorrhage present in A–29, and the purulent bronchiolitis, lobular pneumonia with a chronic proliferative type of inflammation which thickens the alveolar walls and obliterates the pulmonary architecture in case P. In view of the proliferative process, it seems pertinent to make special reference to the pneumoconiosis present in these two cases.

There is evidence that the deposits of dust possess a capacity to irritate the pulmonary tissue. In both instances, it is only mild and without the development of fibrous tissue and hyalinization characteristic of the reaction to free quartz. The irritation is most pronounced in case P, where dust-filled macrophages are localized in the thickened alveolar walls. In case A–29 it is less evident and impossible to differentiate from the chronic response resulting from the purulent process in the lung.

In addition, both cases show fine black particles of dust widely dispersed throughout the pulmonary parenchyma. This is less evident in A–29 apparently because of the extensive acute inflammation present. However, there is no detectable inflammatory response which might be specifically due to these particles. Thus, this feature in these two cases is again not unlike that present in the first three cases, which died during the acute phase of the incident.

Similar comparison is impossible with other organs. However, certain findings are worthy of comment insofar as they may have bearing on the pulmonary pathologic conditions. The comments are as follows:

Case No. 3.—The small tubercle in the lung is apparently healing and shows no evidence of reactivation. The epiglottis and trachea are without significant abnormality. The heart is not enlarged, but there is evidence of coronary disease of moderate degree and also generalized vascular disease which involves especially the kidneys. The liver reveals mild chronic inflammation of the portal areas.

Case No. 15.—The trachea shows no change. The heart is enlarged and there is evidence of coronary disease. The aorta shows extensive atherosclerosis, but the kidneys remain uninvolved. The liver reveals mild, chronic inflammation of the portal area.

Case No. 2.—The heart is hypertrophied with incompetency of the mitral valve. The liver shows moderately advanced cirrhosis. The kidneys reveal advanced nephrosclerosis.

Case A–29.—The heart is moderately enlarged with slight fibrosis of the myocardium. The liver reveals chronic passive congestion. The kidneys exhibit moderately advanced nephrosclerosis.

Case P.—The liver exhibits mild central degeneration, probably the result of chronic passive congestion.

Discussion of autopsy findings.—The evidence derived by autopsy discloses that the larynx, trachea and bronchi of the first order were little affected. Apparently, the irritating agent was carried into the lung and exerted its primary effect upon the terminal bronchi, the bronchioles and the pulmonary parenchyma. However, that agent must have had a low irritating capacity since none of the cases exhibited a degree of haemorrhage, oedema or necrotizing process commonly associated with the inhalation of lethal irritating substances.

Analogy might be made here with certain war gases. Phosgene, for example, has little effect upon the upper respiratory tract. The finer bronchi and lungs undergo an intense oedema and congestion during the acute phase of the poisoning. Later, a purulent bronchiolitis supervenes with spread of the exudate for a variable distance into the surrounding alveoli. When death is delayed after exposure to the gas, infection of the respiratory tract is the cardinal change found.

It is true that the autopsied cases under review manifested evidence of severe infection. The relationship of that infection to the incident remains questionable. The development of purulent bronchiolitis and lobular pneumonia within 3 days of exposure is viewed with suspicion. Both processes were far more advanced than expected for a substance capable of producing the limited haemorrhage and oedema present. Furthermore, even though both processes were present in the two persons who died later on, and dominated the pathological change presented by one, the fact still remains that purulent bronchiolitis and lobular pneumonia are frequent findings in the lungs of individuals coming to autopsy and having no known contact with the inhalation of industrial substances. Again, if purulent bronchiolitis and lobular pneumonia were the residual effects of the incident, it seems reasonable to assume that similar effects should be present also in a host of other individuals in the population exposed. This, however, does not appear to be the case. Sampling, based on roentgenographic evidence, not presented in this

preliminary report, indicates that a large percentage of that population is without significant pulmonary abnormality.

Scrutiny of the autopsy protocols indicates that the majority of cases suffered from extrapulmonary disease not unlike that found in elderly individuals and often primarily responsible for death. This point has reference to the cardiovascular renal disease which in the early cases, at least, could not have developed within as short a time as three days. Similar pathologic conditions were present also in one of the later cases. The composite of these findings indicates the presence of a generalized cardiovascular disease. In view of the above, it seems reasonable to conclude that chronic diseases of a nature barring any relationship to the incident were operating in the apparent selection for the etiology of mortality.

The isolated particles discovered within the macrophages and connective tissue framework of the alveolar walls of the cases studied may have some bearing on the mechanism to explain the biological aspects of the incident. Thought in this regard is admittedly speculative. Is it possible that the isolated particles by reason of adsorption might have carried a substance into the lung, thus concentrating an otherwise nonlethal level of that substance present in the atmosphere breathed by the fatal cases? Any answer to this inquiry will obviously be complicated and incomplete by reason of the following: Such isolated particles are present in the lungs of practically all cases having exposure to dust. Their presence as isolated particles rather than as mobilized masses within the lymphatic channels does not preclude deposition through recent inhalation such as might have occurred in the three cases which died during the smog. Again, there is no evidence that the isolated particles had a local effect which might be expected had they carried an irritating substance into the lung. Furthermore, tissues other than the lung showed no damage due to adsorbed substances possibly released from those particles and distributed systemically.

It appears, therefore, that some substance was present in the atmosphere inhaled, that that substance irritated the lungs, and that death occurred in certain individuals who were more vulnerable to low levels of such irritation by reason of preexisting chronic disease unrelated to the incident.

Summary

The findings may be briefly summarized as follows:

1. Only in degree of severity and outcome were the fatal cases different clinically from the severely ill cases who did not die.

2. Factors possibly influencing the fatal outcome included age, place of residence (limited only to Webster as compared to Donora), color, and previous health status.

3. Among the factors which apparently did not influence the fatal outcome were included sex, previous occupational status, and duration of residence in the community.

4. Study of the fatal cases according to duration of illness appeared to show no valid differences between those that lasted less than 24 hours and those that lasted a longer period of time.

5. Pathologically, the autopsies of three persons who died during the smog showed acute changes in the lungs characterized by capillary dilatation, haemorrhage, oedema, purulent bronchitis, and bronchiolitis.

6. Chronic cardiovascular disease, the origin of which antedated the smog incident, was a prominent feature of the autopsied cases.

Case Descriptions

Case No. 1, age 64, male, Negro, widower, was born in the United States and came to Donora 30 years ago. His previous occupation, prior to his working as a rod mill laborer in Donora, was all in farm work.

He became ill on day No. 2 at 9 a. m. while at the plant (Rod Mill No. 3). This happened while he was cleaning scale. The illness began with dyspnoea. He became progressively worse and at 3 p. m. was taken to the medical department of the plant. From here he was transported to the plant physician's office where he was given a prescription for oral medication and sent home. At home his dyspnoea continued and he became orthopnoeic. He took his medication by mouth, this medication consisting of antispasmodics. At 7 p. m. he fell asleep and his breathing became more difficult and more shallow and he died on day No. 3 at 5 a. m.

His previous medical record indicates that he had had attacks of dyspnoea associated with smogs. His physician had given him adrenalin and morphine for these attacks and believed that they were due to bronchial asthma. Cause of death was probably bronchial asthma with right-sided heart failure.

Case No. 2, age 84, male, widower, white, was born in Austria and arrived in the United States 40 years before. He resided in the Donora area for the past 10 years. His sole occupation in this country was coal mining from which he had retired about 10 years before.

He became ill at 5 p. m. on day No. 2, with a productive cough, dyspnoea, and orthopnoea. The following morning his "chest appeared fixed in inspiration," his respirations were rapid and shallow and his color was extremely pale. He received no medical attention and died at 3 p. m. on day No. 3.

His past medical history indicated that he was known to have had heart failure with auricular fibrillation in 1947 and in early 1948.

Autopsy

Autopsy was performed 8 hours after death.[11]

The body was that of a rather poorly developed white male. Examination of the right lung showed dense adhesions of the pleural membranes over the thoracic cage to the diaphragm throughout the mediastinal space. Grossly this lung was intensely congested and oedematous. Grossly, emphysema was present. There were numerous small hard black nodules scattered through both lungs. The pleural membrane was densely thickened.

The left lung was collapsed. This lung was extremely oedematous. Otherwise it was similar to the right lung.

The heart was markedly hypertrophied. Both auricles were dilated. The coronary arteries were patent and showed very little evidence of atherosclerosis. The mitral valve was incompetent due to shortening and adhesions of the chordae tendinae. The valve leaflets were thickened, and the left leaflet was markedly shortened. The left ventricle was 3 cm. in thickness and the right 0.5 cm. The aortic and tricuspid valves were essentially normal. There was only a moderate atherosclerosis of the aorta.

The liver was pale and of approximately normal size. Sections of the liver showed thickening of the capsule and cirrhosis extending 1 cm. in depth.

Sections from the kidneys showed a moderate nephrosclerosis of the arterial type.

Examination of the blood sample showed it to be dark in color. The specimen had a strong acid reaction, but this was probably largely due to the formaldehyde used in the embalming fluid.

The autopsy diagnosis, based essentially on gross findings, was anthracosilicosis, cardiac hypertrophy with arteriosclerotic heart disease, and generalized arteriosclerosis.

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[11] The autopsy was performed by Dr. G. W. Ramsey of Washington, Pa. Findings in the study of microscopic sections of lung, liver, and kidney were prepared by Dr. Arthur J. Vorwald.

Microscopic Examination

The microscopic examination of tissue was as follows:

Lung.—The most significant abnormalities present in sections examined have reference to mild vascular congestion with focal oedema, bronchiolitis, pneumoconiosis, and emphysema.

Many of the large vascular channels are distended with blood indicative of congestion. However, this is focal as it involves only portions of the capillary system within the alveolar walls. There is also a focal oedema as evidenced by pink-stained precipitate in some of the alveolar spaces of two sections of pulmonary tissue. The remaining two sections do not demonstrate such alveolar precipitate. In addition, few of the spaces, particularly about widely distended, thin-walled, vascular channels, contain an occasional erythrocyte, but this is not at all a prominent feature. The precipitate is generally acellular.

In general, the vascular channels are normally thin-walled. Only an occasional arteriole shows slight intimal or medial thickening. Differentiation here cannot be done for lack of tissue preparations with special stains. All channels are widely patent. There is no evidence of thrombosis or embolization.

In some of the sections the alveolar spaces are considerably distorted and often distended. The process is especially pronounced in at least two of the tissue sections where many alveolar walls are ruptured giving rise to large spaces as seen in an emphysematous lung. Not all such large spaces, however, can be interpreted as pathological since some represent a minor lobule with atria into such lobules clearly defined. Distortion and obliteration of spaces occur in patches, especially in areas of pigmentation.

The alveolar walls are generally thin, and without significant cellular infiltration or histiocytic proliferation. Here and there within the walls, and often attached to the surface of the air space, there are few widely scattered small black particles, most of which are within large phagocytic cells. Otherwise, there is no detectable associated cellular reaction to such particles. In addition, there are masses of black pigment localized mainly in the connective tissue sheaths about the larger vascular channels and the bronchioles. Similar deposits are also present in the pleura and interlobular septa. There is slight proliferation of connective tissue about such deposits, which indicates that the pigment has mild degree of toxicity, but no more than commonly associated with an inactive dust. There is one exception in that one section contains an isolated subpleural nodule of pigmented whorled hyalinized fibrous tissue, typical of the reaction to free silica.

The sections contain only a very occasional bronchiole. The lumina are patent, but contain a few desquamated epithelial cells, and a small number of inflammatory cells. These features are not at all prominent. The basement membrane is only slightly thicker than normal. The bronchiolar musculature is not unduly prominent. The connective tissue in the wall is only slightly infiltrated with lymphocytes and plasma cells, and a rare leukocyte. Eosinophilia is not a prominent feature. Photographs of microscopic sections appear in figures 26–29.

Liver.—The capsule is slightly thicker than normal. In addition, the majority of portal areas exhibit significant proliferation of connective tissue with moderate infiltration of chronic inflammatory cells. The bile ducts are few in number, and their lumina are somewhat constricted. There is only mild fatty metamorphosis of the parenchymal substance. The findings described above are compatible with a diagnosis of moderately advanced portal cirrhosis.

Kidney.—The section exhibits moderately advanced nephrosclerosis as evidenced by intimal change in the arterial walls with constriction of the respective lumina, intertubular proliferation of connective tissue with mild round cell infiltration, scattered tubular degeneration and hyalinization of an occasional glomerulus. Otherwise, there is no evident glomerular or tubular damage identified as possibly resulting from a known toxic agent.

Spectrographic Analyses.—A sample of lung was analyzed spectrographically in another laboratory. The liquid was extracted from the spongy tissue by the use of pressure with glass rods, and both the liquid and the spongy tissue were then ashed at 500° C. in the presence of a small amount of sulfuric acid. Ten mg. of the ash were arced in a manner used for qualitative spectrographic analysis.

The elements detected are shown below. It is exceedingly doubtful if the amounts noted of those elements with toxic qualities could have had any pathological-physiologic effects.

Relative concentrations (Total of elements reported=100%)	Elements detected in lung sample	
	Ash of tissue	Ash of liquid
Over 10 percent	Iron. Silicon. Sodium. Calcium.	Sodium. Potassium.
1 to 10 percent	Potassium. Aluminum Phosphorus. Titanium.	Calcium. Aluminum.
0.1 to 1 percent	Magnesium. Boron.	Phosphorus. Iron. Boron. Silicon. Magnesium
0.01 to 0.1 percent	Zinc. Chromium. Copper. Barium. Strontium. Lead. Lithium. Manganese.	Copper. Titanium Chromium. Zinc.
Less than 0.01 percent	Tin. Gallium. Nickel. Cadmium. Vanadium. Molybdenum. Silver.	Vanadium. Manganese. Strontium. Barium. Nickel. Lead. Lithium. Molybdenum.

Case No. 3, age 69, white, male, widower, was born in Czechoslovakia. He came to the United States 46 years ago and thereafter always lived in Donora where he worked in a local wire plant. He was pensioned on account of age, 3 years previously.

His illness began on S-day at 3 p. m. with a mild attack of dyspnoea which subsided rather quickly. He was well on day No. 1. On day No. 2, at 5 p. m. while resting on the porch of his home he suddenly developed by dyspnoea and orthopnoea. He did not cough. A physician gave him an injection which afforded some slight relief. He also received medication by mouth. At 7:30 p. m. his dyspnoea seemed to be aggravated and at this time it was noted that his abdomen was distended. He could not sleep because of his orthopnoea and dyspnoea which progressed until he died at 6 a. m. on day No. 3.

His past medical history appears to be entirely negative except that he was said to have had some dyspnoea associated with fog. He was not known ever to have had heart disease, bronchial asthma, or chronic bronchitis.

Autopsy

His body was disinterred and an autopsy was performed 5 months after his death.[12]

The gross findings were as follows:

External description.—The body is that of an adult, well built and obese, white male appearing about 65 years of age, weighing about 230 pounds and measuring about 5 ft. 9 in. in height. It is firmly embalmed and cold. The head is covered with a good amount of grey hair. There is nothing remarkable about the scalp externally. The lids of the eyes are firmly closed. The ears reveal no gross abnormality. The nasal orifices are patent and the septum is intact. The teeth and gums are in bad condition. The neck is thick. The chest is normal in contour. The abdomen is normal in contour, and palpation is of no avail because of firm fixation. The external genitalia show

[12] The autopsy was performed by Dr. Arthur J. Vorwald.

post-mortem change, being black in color and distorted by drying. The testes can be palpated in the scrotal sac. The hands projecting from the suit coat also show post-mortem change. Firm pressure over the dorsum of the feet and legs leaves the impression of the finger, but this is true generally for the whole body, and is interpreted as the result of embalming and post-mortem change, rather than ante-mortem oedema.

Midline incision reveals a firm subcutaneous layer of yellow adipose tissue which measures 3 cm. in thickness just below the umbilicus.

Abdominal cavity.—The abdominal cavity is free of fluid and adhesions. Puncture marks of the embalmer's trochar are found everywhere. The peritoneal surfaces are smooth and glistening. The liver is above the costal margin in the right midclavicular line. The gall bladder is collapsed and free of adhesions. There is a strange anatomical disarrangement of tissue in the upper abdominal cavity, insofar that a portion of the fatty omentum and stomach penetrate the diaphragm into the thoracic cavity. This finding is described in greater detail below. The omentum is extremely rich in fat. It covers the entire bowel. The latter is normally disposed. The caecum is normally free as is the appendix. The mesentery is extremely thick with fat which obscures all the contained lymph nodes and vascular trunks. The spleen is adherent posteriorly. There is nothing remarkable in the pelvis.

Diaphragm.—Right—3d interspace; left—4th rib. The diaphragm is damaged in numerous spots with trochar puncture tears which range from 6 mm. to 5 cm. in diameter. These tears involve mainly the midportion of the structure. Where these tears are over the right major hepatic lobe, small mushroomlike portions of the liver project through them into the right thoracic cavity. The pleural surface of these portions is smooth. That portion which projects through the large tear measures 4 by 5 by 2.5 cm., and exhibits a constriction ring about its base. In addition to the above, there is another large tear in the midportion of the diaphragm through which almost the entire left lobe of the liver, most of the stomach and a mass of fatty omentum project into the pericardial cavity.

Inspection of the margin of each of these diaphragmatic defects discloses them to be rough and ragged. This observation is not in accord with the smooth and glistening margin of an ante-mortem diaphragmatic herniation. In view of the above findings, defects described above are interpreted as post-mortem artefacts.

Pleural cavities.—The pleural cavities are free of fluid. There is a tough fibrous adhesion posteriorly on the left. Otherwise, the lungs are free. Except for the diaphragmatic tears described previously, the visceral and parietal surfaces are smooth and glistening.

Pericardial cavity.—In consequence of the post-mortem tears in the diaphragm and the evulsion of portions of the abdominal organs into the cavity, the heart is pushed up and rotated to a transverse position. In addition, the ascending aorta within the cavity is kinked upon itself forming two complete folds which obstruct the lumen. This observation is believed to be absolutely incompatible with cardiac function and supports the interpretation that the diaphragmatic defects are post-mortem tears rather than ante-mortem herniations.

Heart.—The heart reveals numerous trochar marks. It is normal in size for the individual and estimated to weigh about 300 gm. The epicardium is smooth and glistening. There are no petechial haemorrhages. The coronary vessels are not unduly prominent. On section, the chambers are empty. The valve orifices and cusps are firm and fixed by embalming in a distorted position. However, the cusps are free, glistening, and smooth. The chordae tendineae and papillary muscles appear normal. The myocardium fails to show evidence of abnormality other than that attributable to embalming. Fibrosis is not detected. The coronary vessels, although followed with difficulty because of the distortion of the organ, are widely patent throughout and show only a very rare focus of atheroma. The wall of the left ventricle at its base measures 2 cm. and that of the right 7 mm. in thickness.

Aorta and major vascular trunks.—The ascending and thoracic aorta are remarkably free of change for a man this age. The abdominal portion reveals an occasional atheromatous plaque the number of which becomes more numerous toward the bifurcation. Here few of the plaques contain calcium. The pulmonary, renal, splenic, and other major trunks are not remarkable.

Pharynx and larynx.—The walls are everywhere smooth and glistening. Haemorrhage or erosion of the mucosa is not detected. The epiglottis is in normal position. It, too, is smooth and glistening. The free margin is slightly puffed, suggestive of underlying fluid. Whether this is ante-mortem or post-mortem must await microscopic study. The larynx fails to show any detectable abnormality. The vocal cords are smooth and appear normal in every respect.

Trachea and main bronchi.—Contain only a small amount of mucus mixed with black pigment. Otherwise the passages are widely patent. The mucosa is pale, smooth, and glistening. There is no evidence of erosion or ulceration.

Lungs.—Except for a tag of fibrous adhesions at the apex of the left lower lobe posteriorly, the pleural surfaces are smooth and glistening. They are uniformly marked with scattered foci of black pigment. These foci do not project above the surface and cannot be felt on palpation. Repeated section of the lung discloses a uniform picture. It is everywhere in good state of preservation. Foci of black pigment are scattered throughout being easily differentiated from the dark background of pulmonary tissue. These foci are soft. In the immediate subpleural zone of the right lower lobe laterally, there is a partially calcified tubercle 5 mm. in diameter. In general, the air spaces are uniform in size and the alveolar walls do not appear thickened. Close inspection reveals occasional pin points of white tissue which are interpreted as vascular walls brought into focus by sectioning. There are also linear foci of similar whiteness which are unmistakably vascular.

Tracheobronchial lymph nodes.—The nodes are only slightly larger than normal. They are loaded with black pigment, but all are soft and fail to reveal evidence of fibrosis.

Esophagus.—The esophagus contains small flecks of brownish granular material, presumably the remains of gastric content. The mucosa is everywhere pale and intact.

Gastrointestinal tract.—The stomach is much distorted, being fixed by embalming in the pericardial cavity as previously described. The wall is torn by embalmer's trochar and the cavity is empty. The mucosa is moderately well preserved. It is pale and smooth. Significant abnormality is not detected.

The intestines reveal no significant pathological conditions. The small bowel is generally empty. Fecal material is found in the colon and portions of this are removed for chemical examination.

The appendix is free and appears normal.

Liver.—The liver is estimated to weigh about 1,700 gm. Although the lobes are distorted as described previously, the surfaces are smooth. The borders are moderately sharp and fail to show the rounding commonly associated with congestion. On section, the markings are ill-defined. They are better preserved in the periphery of the organ. Here there are no detectable pathological conditions.

Gall bladder and bile ducts.—The viscus is collapsed and in advanced post-mortem state. Concretions are not discovered. The ducts do not reveal detectable ante-mortem pathological conditions.

Spleen.—The organ is dark red and fixed by embalming in a distorted and firm state. It is normal in size with an estimated weight of 130 gm. On section, the markings cannot be identified in the gross because of post-mortem change. Only a few scattered Malpighian corpuscles are detected in the immediate subcapsular area.

Pancreas.—The pancreas is embedded in a very thick coat of firm adipose tissue. On section, the organ is firm and well preserved. There is no detectable abnormality.

Kidneys.—The kidneys are embedded in a very large amount of firm adipose tissue. Removal of this discloses pale red-tinged organs. The left is slightly larger than the right. The estimated weights are 200 gm. for the left and 175 gm. for the right. The capsule on each is unduly adherent and strips wtih difficulty. The surfaces are irregular with gross depressions. In addition, they are mildly pitted and coarsely granular. A very occasional small cyst projects above the surface. On section, the cysts are confined to the cortex and contain clear fluid. They measure from 1 to 3 mm. in diameter. There is fairly good differentiation between cortex and medulla. The cortical markings are less defined than normal. The pelvis of each organ is filled with fat. The pelvic vessels and ureters are not remarkable.

Adrenals.—The adrenals are embedded in fat. They are equal in size, and fail to show any detectable gross abnormality of significance. The cortex is thin and retains a light yellow color.

Urinary bladder, prostate, and reproductive organs.—Were not removed because of technical difficulties. In situ, incision of the bladder does not show any significant change. By palpation the prostate is only slightly larger than normal.

Brain.—Reveals post-mortem change. Section fails to disclose other abnormality.

The anatomical diagnosis was:

Moderate anthracosis of the lungs and tracheobronchial lymph nodes with hyperplasia of the latter; left focal fibrous pleuritis; isolated, partially calcified tubercle in the right lower lobe; mild atheromatous degeneration of the coronary vessels; atherosclerosis of the abdominal aorta; moderate nephrosclerosis, with cystic degeneration; and generalized post-mortem change.

Microscopic Examination

Heart.—The muscle fibers and nuclei are in a surprisingly good state of preservation. The interfibrillar connective tissue is somewhat diminished, perhaps the result of post-mortem change. The fibers and bundles of muscle exhibit a uniform pattern consistent with the normal state. There is no evidence of fractionation or of significant fibrosis. The muscle nuclei are not unduly enlarged. The epicardial fat reveals some post-mortem change characterized by loss of architectural detail and poor staining. For the most part, however, the fat globules are clearly defined. Although such fat extends often between the myocardial bundles, yet such infiltration is only very minimal and without significance. The coronary vessels contained in the sections examined exhibit moderately advanced atheromatous change involving the intimal and medial coats of the vessel wall. In consequence, the lumen of the vessel is constricted, however, a vascular channel of good size is still present in each vessel observed.

Aorta.—The aorta exhibits moderately advanced atheromatous degeneration of the intima and media. The degenerative change is accompanied by mild infiltration of round cells, and shows also scattered fat vacuoles and few cholesterol slits. The latter are found mainly in the medial layer of the wall and some such areas contain widely scattered granules which take the hematoxylin stain and which are interpreted as calcium. The vasa vasorum are often distended with blood. Only a very occasional one is surrounded by a thin perivascular zone of lymphocytes. However, this is not enough to suggest a luetic process.

Epiglottis.—The epiglottis is covered with a layer of epithelium which on the pharyngeal side is squamous in type. This merges finally with that of the columnar type which lines the laryngeal side of the structure. The epithelium is everywhere smooth, intact and fails to show any detectable abnormality. The subepithelial connective tissue exhibits the usual amount of lymphoid tissue which is loose in structure but without evident hyperplasia or inflammation, either acute or chronic. Elsewhere the connective tissue fibers are separated, but not sufficiently to suggest the presence of oedema. The mucus glands, fat tissue, and cartilage within the structures do not show significant abnormality. There is no evidence of "inflammation."

Trachea.—Sections fail to show any significant abnormality. The mucosa is intact and the underlying structures are not remarkable for the age of the individual.

Lungs.—The intrapulmonary bronchi and bronchioles contained in the sections exhibit profound changes which are both acute and chronic. The larger passages, primarily those with cartilage are partially or completely occluded by masses of columnar epithelial cells. Such masses often merge imperceptibility with the hyperplastic mucosal lining of the passage. In addition to the above, many such masses contain also much mucous and scattered inflammatory cells and finely dispersed particles of black pigment. The inflammatory cells infiltrate also the mucosal layer and often form a subepithelial zone which separates the mucosa from the basement membrane. In some of the passages there are wide gaps in the mucosa. Many such gaps result from detachment of the epithelial layer. However, such detachment is not the case in many gaps where the mucosa is absent by reason of ulceration. The mucosal and submucosal capillaries, especially of the intrapulmonary bronchi are dilated and distended with blood. In addition, the capillaries in the parenchyma immediately about the bronchi often show similar changes. The basement membrane is appreciably thicker than normal and often with structural detail suggestive of ante-mortem hyalinization. The muscle bundles are hypertrophied to such extent that they often cause the wall to bulge into the lumen of the passage. The intervening connective tissue is loose and diffusely infiltrated with inflammatory cells, including lymphocytes, large mononuclear cells and leukocytes. The latter are predominantly of the neutrophilic type. Only an occasional eosinophile is found. The bronchioles exhibit many of the above changes, including focal ulceration of the mucosa.

The parenchyma of the lung shows changes easily recognizable in the gross section. Microscopically, the changes are both acute and chronic. The acute is characterized by focal haemorrhage in some of the alveoli and a peribronchiolar accumulation of inflammatory cells. In addition, few of the air spaces contain a pink-stained, slightly granular material suggestive of oedematous precipitate. Oedema, however, is not a prominent feature.

The chronic change is diffuse in character. It is mainly proliferative in type consisting of lymphocytes, large mononuclear cells and leukocytes. This reaction thickens the alveolar walls and in places obliterates the alveolar structure. Elsewhere, particularly in the subpleural zone and also about many bronchioles, the alveolar walls are ruptured and the air spaces are enlarged suggestive of emphysema.

All sections reveal also the presence of particulate matter. It is found as isolated particles of black or blackish-brown pigment widely scattered in the purulent material filling the bronchi and bronchioles, as well as in the alveolar walls, especially those thickened by cellular reaction. Most such particles are found within large mononuclear phagocytes. Occasionally, they occur also within polymorphonuclear leukocytes, as seen in the purulent exudate filling in bronchioles and bronchi. In addition, black pigment also occurs in masses which are localized in the perivascular and peribronchiolar sheaths of connective tissue, and in the interlobular septa. These masses fail to show an associated inflammatory reaction, at least no more than might be expected from an inert dust.

A section from the right lower lobe exhibits also a well-defined lesion 5 by 5 mm. consisting mainly of a thick peripheral zone of mature hyalinized tissue with a central area of necrosis which contains deposits of calcium. Immediately about the necrosis there are scattered deposits of black pigment. Similar deposits occur also about the periphery of the whole lesion described. About 3 mm. from that lesion there is another small lesion with a central area of bone formation. It is of academic interest to note here scattered small masses of black pigment in the walls of the fat cells within the canal of that formation.

Tracheobronchial lymph nodes.—The nodes are diffusely infiltrated with black dust pigment but without significant reaction, which here also is no more than to any dust with a low index of irritation. The germinal centers in the extrapulmonary nodes are moderately hyperplastic and the sinuses are distended, some with homogeneous pink-staining material, others with red blood corpuscles and scattered mononucleated leukocytes and phagocytes with dust pigment.

Diaphragm.—No significant abnormality is noted.

Intestines.—No significant abnormality.

Pancreas.—Post-mortem change; otherwise nothing remarkable.

Liver.—The capsule is smooth. The parenchyma exhibits moderately advanced fatty metamorphosis, slightly more pronounced about the periphery of the lobules than elsewhere. An occasional triadal area shows an excess lymphocytic and mononuclear cell infiltration. In all instances, this is very mild, but it suggests at least some pericholangitis. Some of the intrahepatic bile ducts are dilated and contain scattered clumps of leukocytes, nuclear debris, and blue-stained masses of bacteria. The presence of the latter is interpreted as the result of post-mortem invasion.

Spleen.—The capsule is moderately thickened. The sinuses of the pulp are distended with blood and the reticuloendothelial elements often contain scattered particulate material of different size and shape and brownish-black in color. The nature of this material cannot be fully determined. However, most of it is identified as haemosiderin. The corpuscular components are not remarkable.

Kidneys.—Except for moderately advanced arteriolonephrosclerosis with scattered simple cysts and some post-mortem change, there is nothing significant microscopically.

Adrenals.—The cortical substance is moderately rich in lipoid substance. There is only very mild post-mortem change.

Brain.—Study of numerous sections fails to reveal any significant abnormality.

Photographs of microscopic sections appear in figures 30–33.

Spectrographic analyses.—These analyses were made of the various organs and other biologic material. Ten-gram samples of tissue were weighed into flasks and acid-ashed with nitric and sulfuric acids. Portions of the dry residual ash were placed in the cupped part of the graphite electrode and exposed spectrographically. The entire range of the spectrum from the infrared to far ultraviolet was obtained with each specimen. The spectrograms were then carefully examined for all lines of any prominence. With reference to the findings described below, it may be noted that those elements to which toxic qualities could be ascribed were, in all cases, present in trace amounts only. It is exceedingly doubtful if these amounts could have had any pathological-physiologic effects.

Material	Found in trace amounts	Found in more than trace amounts
Right lung	Copper, calcium, cadmium, aluminum, tin, sodium, zinc.	Iron, boron, silicon, magnesium, phosphorus.
Right lung, anterior.	Copper, sodium, zinc, calcium, aluminum, tin, titanium, cadmium.	Iron, boron, phosphorus, magnesium, silicon.
Left lung	Copper, zinc, aluminum, cadmium, calcium, lead, silicon, tin.	Phosphorus, boron, iron, sodium, magnesium.
Liver	Zinc, silicon, lead, tin, cadmium, aluminum.	Iron, boron, magnesium, phosphorus, sodium, copper.
Kidney	Copper, zinc, lead, silicon, aluminum.	Boron, phosphorus, magnesium, sodium, cadmium, iron.
Intestine	Iron, copper, zinc, cadmium, aluminum, manganese, tin, lead.	Boron, sodium, phosphorus, magnesium.
Fecal matter	Silicon, zinc, calcium, aluminum, cadmium, lead, tin.	Phosphorus, boron, magnesium, copper, sodium.
Brain	Iron, copper, calcium, potassium, zinc.	Sodium, phosphorus, boron, magnesium.

Case No. 4, age 62, female, white, married, was born in Czechoslovakia. She came to the United States 42 years ago and always lived in the Donora area.

Her illness started on day No. 2 at 6 p. m. while working at home. Illness began with a dry cough and dyspnoea. Her physician treated her with a hypodermic injection and some medication by mouth. The cough diminished but she was unable to sleep because of increased severity of dyspnoea. During the evening she also developed orthopnoea. She became very weak and died on day No. 3 at 8: 30 a. m.

Her previous history was negative. She never had heart disease, chronic bronchitis, or bronchial asthma.

Cause of death was recorded as asthma.

Case No. 5, age 52, male, widower, white, was born in the Donora area where he lived most of his life. He was employed as a coal miner from his youth and was forced to retire about 14 years ago because he was said to have had heart disease.

His illness started with severe dyspnoea about 6: 30 a. m. on day No. 3 while lying in bed. He became extremely orthopnoeic and markedly cyanotic. He received no medical attention and died at 11: 30 p. m. on day No. 3.

According to the informant he had spent the past few years in bed because of his dyspnoea and muscle weakness. Between 1 and 2 years ago he was placed in a hospital with a diagnosis of pneumonia. He was hospitalized there for 3 months.

The cause of his death was heart disease with heart failure.

Case No. 6, age 55, female, Negro, married, was born in the United States and lived in Donora for some 16 years.

She became ill about 10 a. m. of day No. 2 with symptoms of dyspnoea and a choking sensation. This was accompanied by a dry nonproductive cough. In the afternoon she developed orthopnoea. A hypodermic injection, given to her by a physician at about midnight of that day gave no relief. She died at 4 a. m. on day No. 3.

She was suspected of having luetic heart disease. She had an "irregular" heart rhythm and a 4+ Kahn reaction. Other than that, she was known to have had mild attacks of dyspnoea associated with foggy weather.

Death was probably due to luetic heart disease with heart failure.

Case No. 7, age 58, female, Negro, widow, born in the United States. She lived in the Donora area 11 years.

She became ill on day No. 2 at 6: 30 a. m. She was awakened out of a sound sleep with an attack of dyspnoea. In the evening she appeared worse and become orthopnoeic. She developed a dry, nonproductive cough and profound weakness. She received no medical attention. Breathing became more labored and shallow and she died on day No. 3 at 2: 30 a. m.

She was known to have had dyspnoea associated with fog for several years. She was treated in the past for bronchial asthma.

Death was due to bronchial asthma and heart disease.

Case No. 8, age 68, white, male, married, was born in Jugoslavia and came to the United States as a youth. He lived in the Donora area for the past 21 years. He was a coal miner until his retirement because of an injury about 18 years ago.

His illness started at 6 a. m. on day No. 2 with shortness of breath and a nonproductive cough. He vomited several times in the afternoon. In the evening his dyspnoea appeared aggravated and orthopnoea developed. He did not receive any medical attention and was unable to sleep. He died at 2: 30 a. m. on day No. 3.

His previous medical history was negative for bronchial asthma, chronic bronchitis, and heart disease.

Death was due to silicosis, heart disease with heart failure.

Case No. 9, age 70, female, widow, white, was born in Scotland and came to the United States 24 years ago. In this country she always resided in the Donora area.

Her illness started with a dry cough and dyspnoea on day No. 1 at 4 a. m. while she was at home. The dyspnoea became worse throughout the day. She was unable to sleep that night; in fact, she was not even able to lie in bed because of orthopnoea which developed. A hypodermic injection given to her in the morning of day No. 2 was without effect as was a second injection given that night. However, her cough subsided somewhat. She became progressively weaker and died at 2 a. m. of day No. 3. She was not noticed to have had any cyanosis.

She was known to have had heart disease with moderate heart failure for the previous 3 years. She was known also, to develop dyspnoea whenever the weather was foggy.

Diagnosis was arteriosclerotic heart disease with cardiac failure.

Case No. 10, age 55, male, Negro, separated from his wife, was born in the United States. He had been unemployed for the past 3 years, reason unknown. The information in his case was obtained from the landlady of the rooming house in which he was living. He had been a resident of the community for 6 years.

His illness began on day No. 1, at about 6 a. m., with symptoms consisting of dyspnoea and a choking sensation. This awakened him from his sleep. He stayed in bed and after a few hours felt sufficiently relieved that he was able to walk six blocks to the business center of the town. There he stayed for 15 minutes returning to his residence by automobile because he developed another episode of acute dyspnoea. His dyspnoea became worse and he developed orthopnoea. He did not cough.

These symptoms continued until about 9 p. m. when he developed a "hot sensation" inside his chest and became increasingly weak. His dyspnoea increased in severity until he was gasping for air. He died at 8 a. m. of day No. 3 without having received medical attention.

His previous medical history indicates that he had been known to have had auricular fibrillation with heart failure in 1944. This had responded to digitalis. In 1946 he was again found to have cardiac failure and his systolic blood pressure at that time was recorded at 200 mm. of mercury.

The diagnosis was heart disease of unknown etiology (? hypertension or syphilis), auricular fibrillation, and heart failure.

Case No. 11, age 70, white, male, single, retired, wire plant worker, was born in Jugoslavia. He arrived in the United States 46 years ago and had always lived in the Donora area since that time.

His illness began with an attack of dry coughing and shortness of breath on day No. 2 at 8:30 p. m. while he was at home. The dyspnoea became worse very rapidly so that by 2 a. m. of day No. 3 he died. It was observed that a white frothy fluid was coming out of the patient's mouth during the last moments of life.

His previous history indicated that he had some symptoms for which a diagnosis of cancer of the stomach was made. This diagnosis had been made 2 years previously. However, he was well during his last 2 years, apparently without any weight loss or any other symptoms referable to the gastrointestinal tract. There was no history of his ever having had bronchitis, bronchial asthma, or heart disease.

His final diagnosis was arteriosclerotic heart disease and heart failure.

Case No. 12, age 66, male, married, white, was born in Scotland and had lived in Donora area since his arrival in the United States 27 years before. In his youth he had been a coal miner and in the years before his death he was suspected of having silicosis. His recent occupation was as a janitor in a local steel mill.

His illness started on day No. 1 at 9 p. m. while walking in the street near his home. This began with dyspnoea and substernal pressure. He felt improved when he entered his house. He apparently slept poorly that night because of dyspnoea. On the morning of day No. 2 he had a severe attack of dyspnoea which lasted several hours. His physician treated him with a hypodermic injection and some medication by mouth. He slept for a while that evening but awakened because of respiratory difficulty. This became more severe and he died at 10:30 a. m. of day No. 3.

His previous medical record indicated that he had silicosis, emphysema, and enlargement of the right side of his heart. He was known to develop severe dyspnoea whenever the days were foggy. On repeated occasions he had received adrenalin or morphine for his severe paroxysms of dyspnoea.

His death was due to cardiac failure, probably secondary to silicosis with an asthmatic component.

Case No. 13, age 81, male, married, white, barber, was born in the United States. He had lived in Donora 45 years.

His illness began on day No. 2 at 1 p. m. with shortness of breath and substernal pressure while he was at work in his barber shop. He was attended by a physician at home who administered a hypodermic injection which gave him slight relief. At about 5 p. m. he was noted to have orthopnoea and cyanosis. Bronchodilators did not relieve his symptoms. At about 8 o'clock that evening he developed severe pain in the lower abdomen, became nauseous, and vomited once. The dyspnoea and orthopnoea kept him awake all night and the next morning it was decided to remove him from the area. He died while en route out of town at 4 p. m. on day No. 3.

He was known to have arteriosclerotic heart disease, with heart failure of a moderate degree. During his acute illness he is said to have had bronchial asthma. Loud musical rales were heard in his chest in his last illness.

His diagnosis was arteriosclerotic heart disease and bronchial asthma.

Case No. 14, age 55, female, white, married, housewife, was born in Austria. She had lived in the Donora area for 42 years.

Her illness began on S-day at 7 a. m. with slight frontal headache which was relieved by aspirin. The next morning, day No. 1, her headache recurred and was more severe and involved the entire head. This continued until she was given some type of parenteral treatment by a physician at 2 a. m. of day No. 2. During the daylight hours of day No. 2 her pain was again severe. On day No. 3 she received further therapy which included some medication by mouth and another hypodermic injection. Her breathing did not become troublesome until about 6 p. m. of that day and she died at 10 p. m. of day No. 3.

Her previous history reveals that she was known to have had fibroid tuberculosis, her sputum on several occasions having been negative. She was known not to have had heart disease or asthma. The cause of death was given as pulmonary tuberculosis and acute tracheobronchitis.

Case No. 15, age 67, white, male, married, was born in Italy. He came to the United States 44 years before and lived and worked as a railroad worker in Donora since that time.

His illness began with dyspnoea and a slight dry cough at 9 p. m. of day No. 1 while he was at home. He slept well that night and felt improved in the morning. On day No. 2 in the afternoon his symptoms recurred and a physician gave him a hypodermic injection which had no effect. His dyspnoea became worse at 7 p. m. and he developed orthopnoea and some cyanosis. He also complained of a sense of fullness in the abdomen and blurring of his vision. He could not sleep that night and awoke in the morning of day No. 3 and collapsed on getting out of bed. He was helped to a chair and then got up and walked around. At 9 a. m. on day No. 3, he was apparently delirious. This cleared by 11 a. m. His respiratory symptoms became progressively worse and he died at 4 p. m. of day No. 3.

He was not known to have had heart disease, bronchial asthma, or chronic bronchitis. It was known that he had had hypertension (180/110 in 1939, and 195/110 in 1945). He was rather a heavy person, weighing 245 pounds. Cause of death was clinically recorded as asthma.

Autopsy

His body was disinterred 5 months after his death and an autopsy was performed.[13]

The gross examination findings were as follows:

External description.—The body is that of an adult white male appearing about 65 years of age. The body is cold and firmly fixed. It is estimated to weigh about 250 pounds and to measure about 5 ft. 6 in. in height.

The head, neck, and hands are covered with a layer of mold about 2 mm. thick. The clothed portion of the body is free of such mold, but the underlying skin exhibits an occasional area of post-mortem discoloration and drying. This is most pronounced about the stomach, the arms and the external genital organs. The scalp is covered with short grey hair. The eyes are sunken in the orbital sockets and are opaque with post-mortem change. There is nothing abnormal about the ears and nose. Fixation of the mouth permits only very slight opening which reveals the teeth in poor state with the root areas exposed because of retraction and post-mortem change involving the gums. The neck is short and thick. Firmness of embalming prevents feeling any abnormality by palpation. The chest is short and barrel-shaped. The abdomen has the normal contour of moderate obesity. It is firmly fixed. An embalmer's trochar mark is in the right upper quadrant just below the rib margin in the mammary line. The skin of the external genital organs is brown-black and partially desiccated.

Midline incision of the trunk reveals 5 cm. of pale but yellow-tinged subcutaneous fat in the anterior wall of the abdomen. The muscles of the anterior chest wall are pale red and well preserved. The same applies also to the exposed abdominal recti.

Abdominal cavity.—The abdominal cavity contains a small amount of clear fluid. Although visualization of the organs in situ is restricted for technical reasons, they appear to be normally disposed. The liver extends about 4 cm. below the costal margin in the right anterior axillary line. The gall bladder is free. The pancreas is not visualized in situ. The omentum is extremely rich in adipose tissue as is also the mesentery. The nodes contained in the latter cannot be palpated. The spleen rests high in the left superior quadrant. The bowel is free. The peritoneal surfaces are smooth. Palpation fails to reveal any abnormality in the pelvis.

Aorta and major vessels.—The aorta exhibits advanced atherosclerosis most pronounced in the abdominal portion. In the latter, there is an occasional small patch of intimal ulceration with underlying calcification. Thrombosis is not discovered in any of the major vessels including the iliac and femoral veins. The pulmonary artery is only mildly dilated, but the walls are not remarkably thickened. The pulmonary vein together with its branches appears unchanged. Other major vessels are not remarkable.

Larynx and pharynx.—Not remarkable.

Trachea and main bronchi.—They contain a small amount of tenaceous mucus which is dark grey, apparently because of scattered

[13] The autopsy was performed by Dr. Arthur J. Vorwald.

particles of pigment. This mucus is scraped from the surface of the mucosa and preserved for chemical study.

Otherwise, these major air passages are widely patent. The mucosa is greyish in color and everywhere intact. There is no evidence of inflammation or oedema.

Tracheobronchial lymph nodes.—The tracheobronchial lymph nodes are only slightly larger than normal. They are black, but generally soft. Section fails to disclose evidence of fibrosis or calcification.

Lungs.—The pleural surfaces, except for tags of fibrous adhesions posteriorly are generally smooth and glistening. In general, the pleural lymphatics are demarcated by scattered foci of black pigment which occasionally extend above the surface of the lung. These foci are linear and round in type. The latter measure from 1 to 4 mm. in diameter. All foci are generally soft. On section, they are thin and involve only the immediate subpleural tissue without the development of nodular lesions typical of silicosis.

The left upper lobe is somewhat contracted, but section discloses a generally air-containing tissue. The alveolar spaces do not appear unduly distended, but everywhere the alveolar walls seem coarser and slightly thicker than normal. Widely scattered throughout the lobe are foci of black pigment. These are most prominent along the grossly visible vascular and bronchiolar trunks, presumably following the course of the lymphatics and concentrated in the intrapulmonary lymphoid aggregates. These foci are slightly firm, but not comparable to that of fibrous tissue.

The interlobar spaces are intact. In general all lobes of the lung resemble the left upper as described above.

Diaphragm.—The leaves are intact. The right is at level of the fourth rib and the left at the fourth interspace.

Pleural cavities.—Both cavities are filled with clear fluid, some or all of which is interpreted as seepage from ground water. Both cavities are obliterated posteriorly by fibrous adhesions. These are most dense and firm about the left apex.

Pericardial cavity.— The pericardial cavity contains an estimated 30 cc. of clear fluid. The surfaces are smooth and glistening. The heart is in normal position.

Heart and major vessels.—The heart is larger than anticipated for a man this age and size. Its estimated weight is 400 gm. The enlargement involves primarily the right side of the organ. The epicardial fat is excessive, but compatible with the generalized obesity. The coronary vessels are not unduly prominent on visual inspection. However, they are easily followed by palpation, being stiff, firm, and cordlike.

Section of the organ reveals post-mortem clotted blood adhering to the inner walls of all chambers, but especially that of the right ventricle. Ante-mortem thrombi are not detected. The valve orifices are widely patent, and the cusps are generally free and intact. The chordae tendineae are stiff from embalming fluid. The papillary muscles are pale. Those of the right ventricle are slightly flattened suggestive of increased vascular pressure within the chamber. The myocardium is generally firm, but pale in color, probably the result of embalming and post-mortem change.

The right-sided enlargement of the organ is due primarily to dilation of the chamber, rather than to pronounced hypertrophy of the muscular wall. The thickness of the ventricular walls measures as follows:

Base of right ventricle, 6 mm.
Midzone of right ventricle, anterolaterally, 4 mm.
Base of left ventricle, 15 mm.
Midzone of left ventricle, anterolaterally, 22 mm.

The measurements of the valve orifices are as follows:

Tricuspid, 10.3 cm. circumference.
Pulmonary, 8.5 cm. circumference.
Mitral, 8.3 cm. circumference.
Aortic, 7.0 cm. circumference.

The coronary arteries are patent throughout, but the orifices and the lumina are constricted by small firm yellow patches of atherosclerosis. Occlusion is not discovered in any of the vessels.

Esophagus.—Not remarkable.

Gastrointestinal tract.—Not remarkable.

Liver.—Except for embalming and post-mortem changes, there is nothing remarkable. The organ is estimated to be normal in size.

Gall bladder and ducts.—Not remarkable.

Spleen.—The spleen is normal in size. It shows embalming and post-mortem changes.

Kidneys.—The kidneys are equal and normal in size. The capsule strips easily leaving a smooth, pale surface. Section shows no significant abnormality.

Adrenals.—Not remarkable.

Urinary bladder, prostate and reproductive organs.—Not examined because of technical difficulties.

Brain.—Not examined.

The anatomical diagnosis was:

Cor pulmonale with dilation of the cardiac chambers on the right, and only mild dilation of the pulmonary artery; mild cardiac hypertrophy; mild pneumonitis of unknown etiology; bilateral fibrous pleuritis; anthracosis of the lungs and tracheobronchial lymph nodes; moderate atherosclerosis of the coronary vessels; advanced atherosclerosis of the aorta; and post-mortem change.

Microscopic Examination

The microscopic examination findings were as follows:

Heart.—The tissue is in good state of preservation. There is no detectable abnormality of significance other than a slight disproportion between the size of the myocardial nuclei and the muscle fiber. This finding suggests mild myocardial hypertrophy. In addition, the coronary vessels included in the sections reveal thickening of their walls and proportionate narrowing of their lumina. This results from atheromatous change involving the intimal and medial coats of the vessel wall. Calcification is not discovered.

Aorta.—The aorta reveals advanced atheromatous change with calcification. There is mild lymphocytic infiltration about the vasa vasorum, but not of sufficient intensity to warrant a diagnosis of lues from microscopic study.

Trachea.—No significant abnormality.

Tracheobronchial nodes.—The tracheobronchial lymph nodes are heavily laden with black pigment which obscures the architecture of the tissue. The pigment is widely distributed and resides mainly within the cytoplasm of cells, but without an associated inflammatory reaction. Thus, the pigment is considered inert. There is no evidence of fibrosis, either silicotic or tuberculous.

Lungs.—The intrapulmonary bronchi and bronchioles contain masses of polymorphonuclear leukocytes mixed with mononuclear cells, and black pigment which occurs as scattered isolated particles, or as clumps. Similar but milder reaction is present also in the wall of these passages where inflammatory cells have infiltrated the epithelial lining and the submucosal tissue. The mucosa is only mildly hyperplastic. In general, it is continuous except for certain anatomical pathways into the alveolar structures. The basement membrane is thin. The peribronchiolar air spaces occasionally contain masses of purulent material not unlike that present within the lumina of the major air passages. Such alveolar masses are interpreted as extensions from the bronchioles.

The microscopic appearance of the pulmonary parenchyma is interesting because it exhibits a number of prominent features. The first of these is the dilation of the vascular channels which is present in all sections examined. The large trunks as well as the alveolar wall capillaries are involved. Many of the latter having no blood often give the impression of thick wall alveolar spaces. Others are filled with red blood corpuscles in various stages of post-mortem degeneration. These dilated vascular channels project very prominently into the adjacent alveolar spaces. The walls of these dilated capillaries are often thick and acellular suggestive of a hyaline change. At times they appear detached from the surrounding connective tissue sheath which may or may not harbor dust pigment. Channels of large caliber, namely, the small arterioles and arteries, are often thick-walled. This apparently results from thickening of all coats since only rarely is the intimal layer specifically involved. The lumina of these larger vascular trunks are generally patent. Occlusion by atheroma or thrombi is not discovered. In view of these vascular changes it is interesting to note that the alveoli are generally empty and without evident precipitate significant of ante-mortem pulmonary oedema.

The second feature of note pertains to the particles of dust within the lung. The pigment is present as large black masses scattered in the peribronchiolar and perivascular sheaths; also in the interlobular septa and occasionally within the framework of an alveolar wall. There is little or no inflammatory reaction associated with such masses of dust which permits its classification as relatively inert. In contrast to these masses, dust is found as isolated small black or blackish-brown particles widely scattered throughout the alveolar walls, and as mentioned previously, in the bronchiolar and bronchial exudate. In most instances these isolated particles are found within cells, usually largely mononuclear in type. Often such dust-laden cells are within the framework of the alveolar wall, or merely attached to the alveolar surface of the space. Identification of the dust scattered as isolated particles is complicated. Most of these are black and irregular in shape and size. Others are blackish-brown, and some of these are undoubtedly haemosiderin. Differential staining demonstrates this, but it also verifies the fact that only very few represent material derived from blood elements. It is difficult to determine the degree of inflammatory reaction possibly resulting from such diffuse localization. In some instances the wall harboring the isolated particles is thin and fails to show evidence of significant cellular accumulation. However, other walls are thickened by large mononuclear cells, and rarely a polymorphonuclear leukocyte. Irrespective of the degree of cellular inflammation present, the alveolar structure fails to show significant proliferation of connective tissue. Fibrosis is not a feature presented by this case. Some of the spaces are distorted because of the cellular reaction in the walls. However, only a very few spaces exhibit evidence of distention or significant contraction. Thus, anatomical evidence of emphysema as demonstrated by dilatation of air spaces is, at best, only minimal.

Thyroid.—The acini are disproportionate in size. Some are small, of the foetal type; others are mildly distended with colloid. The acinar epithelium appears normal. There is no evidence of inflammatory reaction.

Intestines.—Sections of small bowel are not remarkable.

Liver.—The liver exhibits mild fatty metamorphosis and slightly increased leukocytic and lymphocytic infiltration about the bile ducts in the triadal areas.

Spleen.—The spleen is in good state of preservation and without significant abnormality.

Kidneys.—The glomeruli are generally intact and Bowman's spaces are clear. The cortex is remarkably free of cellular or fibrous tissue scars. The tubular structures fail to reveal significant abnormality.

Photographs of microscopic sections appear in figures 34–39.

Spectrographic analyses.—These analyses were made of the various organs and other biologic material submitted to us for study. Ten-gram samples of tissue were weighed into flasks and acid-ashed with nitric and sulfuric acids. Portions of the dry residual ash were placed in the cupped part of the graphite electrode and exposed spectrographically. The entire range of the spectrum from the infrared to far ultraviolet was obtained with each specimen. The spectrograms were then carefully examined for all lines of any prominence. With reference to the findings described below, it may be noted that those elements to which toxic qualities could be ascribed were, in all cases, present in trace amounts only. It is exceedingly doubtful if these amounts could have had any pathological-physiologic effects.

Material	Found in trace amounts	Found in more than trace amounts
Right lung	Copper, calcium, cadmium, tin, zinc, sodium, titanium.	Iron, boron, silicon, magnesium, phosphorus, sodium, aluminum.
Left lung	Copper, silicon, zinc, cadmium, aluminum, tin, lead.	Iron, boron, sodium, magnesium, phosphorus.
Mucus (bronchial)	Boron, phosphorus, magnesium, iron. silicon, copper, cadmium.	
Liver	Iron, copper, potassium, zinc, cadmium.	Phosphorus, boron, magnesium, sodium.
Kidney	Copper, zinc, lead, silicon.	Boron, phosphorus, sodium, cadmium, magnesium, iron.
Spleen	Silicon, copper, calcium cadmium, zinc, lead, tin.	Phosphorus, boron, iron, sodium, magnesium.
Intestine	Iron, copper, cadmium, zinc, lead, tin, manganese, aluminum.	Boron, sodium, phosphorus, magnesium.

Case No. 16, age 66, white, male, married, was born in Russia. He came to the United States in 1904 and lived and worked in Donora since that time, last occupation was in the open hearth department of the steel plant. He retired 1 year ago because of age.

He became ill at 7 p. m. of S-day with dyspnoea while at home. He appeared improved on day No. 1. On day No. 2 at 7:30 a. m. he had an attack of severe chest constriction. He had a recurrence of dyspnoea and developed orthopnoea, severe pain along the costal margins, and a dry cough. The records of the attending physician indicate that on day No. 2 he was cyanotic, his respirations were shallow and rapid, and he appeared in shock. Breath sounds were not audible, and his radial pulse and heart sounds were imperceptible. Blood pressure readings were unobtainable. His physician gave him antispasmodic drugs which gave him transient relief but symptoms recurred on day No. 3. He was taken to a hospital about midnight where he was placed in an oxygen tent until his death which occurred at 12:30 p. m. on day No. 4.

His previous medical history was negative.

The cause of death was recorded as chronic myocarditis, acute tracheobronchitis.

Case No. 17, age 56, male, Negro, married, was born in the United States and came to the Donora area 30 years before. His last occupation was coal mining in which he worked for 40 years.

He became ill on day No. 2, at 4 p. m. while walking home from work. The illness began with severe headache and pain in the region of the umbilicus. This progressed and was treated by a physician the following morning with no improvement. He died at 5 a. m. on day No. 4. He did not have dyspnoea or cough.

His previous medical history reveals that he had had mild attacks of dyspnoea associated with fog. There is no evidence to show that he had had heart disease, bronchial asthma, or bronchitis.

Cause of death was recorded as bronchial asthma and acute tracheobronchitis.

Case No. 18, age 81, white, male, widower. He was born in England, and came to the United States about 65 years before and lived in Donora most of that time. He was a retired coal miner, having been a miner for some 60 years.

His illness began with shortness of breath at 4 a. m. on day No. 2. He also had orthopnoea, as well as substernal sensation of tightness. He apparently improved some for the next few days with medical care and had a severe attack again on day No. 4 at 5 a. m., at which time he was delirious and disoriented. He was taken to a hospital where he was placed in an oxygen tent until his death, which occurred at 5 a. m. on November 8.

His hospital record indicates that he had marked dyspnoea and cyanosis. Examination of the chest revealed a large number of coarse moist and musical rales. Heart examination revealed only an irregular rhythm, with a rate of 120. His temperature on admission was 103.9° F. and this dropped rapidly to 99° F. His respirations were rapid. An X-ray of the chest taken on second hospital day showed calcification of aortic knob with an enlarged heart; lungs showed stage 2 nodular silicosis. (See fig. 22.) He continued to go downhill during his hospital stay in spite of all therapy directed at his dyspnoea. No other abnormal findings were noted and he died with a diagnosis of arteriosclerotic heart disease and heart failure.

Case No. 19, age 65, white, male, widower, was born in Poland. He came to the United States 46 years ago and lived in Donora since that time. He worked in the wire plant and was pensioned 2 years previously because of "an asthmatic condition which was aggravated by fog and smoke."

No data are available on his last acute illness. He died at 11:30 a. m. on day No. 3 and the death certificate lists the cause of death as asthma.

Case No. 20, age 64, white, male, married, was born in Austria. He came to the United States 40 years ago and lived in Donora during the last 37 years. He was employed as a fireman in the wire plant.

No data are available on the clinical history of his illness.

His death certificate indicates that he died on day No. 3 at 7 a. m., and the cause of his death was listed as pneumonia and tuberculosis.

In June of 1949, 8 months after the smog episode, a resident of Donora who was said to have been ill during the October 1948 smog, died as a result of cardiac failure. An autopsy was performed on the body, and certain organs were studied by us for comparative purposes.[14] Case description follows:

Case P, age 42, male, white, married, wire plant employee, lived in Donora all his life.

For the 7 years before his last illness he had had attacks of paroxysmal dyspnoea relieved by adrenalin. He was said to have had a severe attack of dyspnoea, cyanosis and cough during the October 1948 smog, and to have been ill for 7 days.

His fatal illness began May 21, 1949, with cough and dyspnoea which was relieved by adrenalin. On May 23, he developed cyanosis and was hospitalized. In the hospital, he was treated with antispasmodics and was given oxygen by tent. Death occurred 9 hours after admission.

Grossly, the anatomical diagnosis was:

Extensive coronary artery disease with calcification; atheromatous occlusion of right coronary artery (old); stenosis of left coronary ostium (old); cardiac hypertrophy and dilatation; chronic passive congestion of lungs, liver and spleen; bilateral pleural adhesions (extensive); fatty changes of liver; obesity.

Microscopic Examination

Microscopically the tissues showed the following, photographs of the tissue sections appearing in figures 44–49:[15]

Lungs.—The most striking abnormality noted grossly in all sections examined is the thickening of the alveolar walls and distortion of the spaces which involve all portions of the parenchyma. Microscopically, it is observed that the thickening is due to proliferative type of reaction consisting of large mononuclear cells, lymphocytes and histiocytes enmeshed in a fine fibrillar network of loose connective tissue. In addition, the process is complicated by the presence of black dust pigment. The pigment occurs as small masses concentrated in the perivascular zones, presumably the lymphatics. More important, however, it is everywhere present as individual, isolated particles and small clumps usually within phagocytic cells.

In places the process described above is so profound as to form large areas without alveolar structure. Other areas exhibit irregular spaces. Some are small and constricted, while others are large by reason of apparent rupture of alveolar walls. Thus, the anatomy of the parenchyma is considerably distorted and frequently obliterated.

The vascular channels are also abnormally prominent. This involves primarily the capillary network of the alveolar walls which are permeated with numerous dilated capillaries. The lumina of many capillaries are empty, but others are distended with blood in various stages of post-mortem degeneration. This feature of dilatation is often most prominent in the peribronchial and peribronchiolar zones, principally in the immediate submucosal regions. The walls of these channels, whether they be capillaries or arterioles, are often unduly thickened. In some instances this thickening is due to intimal involvement. Special preparations disclose also some increase in the connective tissue elements. In general, however, the whole process of thickening is so mild that intimal fibrous proliferation cannot be differentiated from a medial hypertrophy. Occlusion of vascular lumina by thrombi or emboli is not discovered.

In addition to all the above changes, there is also an occasional focal area in which the alveolar spaces are filled with purulent exudate. Often this exudate is identified as an extension from connecting respiratory bronchioles. Many of these bronchioles are occluded by exudate indicative of a focal purulent bronchiolitis. The larger bronchioles and bronchi reveal profound desquamation of the epithelium, frequently to such a degree that the lumina of these passages are occluded by epithelial cells. Polymorphonuclear leukocytes and dust-filled phagocytes are scattered among these cells.

Tracheobronchial lymph nodes.—These nodes contain scattered masses of black pigment. Here too there are many isolated, blackish-brown particles within individual cells. The vascular channels within the node are very prominent, being distended with blood. Here and there are small focal areas of pink-stained precipitate suggestive of mild oedema.

Within the center of the node there is an appreciable connective tissue proliferation about some masses of dust. However, mature fibrosis is not evident and the reaction is identified as characteristic for a dust with mild toxicity. Whether the dust is responsible for this change is questionable since a similar change is not found in the peripheral portion of the node also harboring large masses of similar dust pigment.

Liver.—The capsule is slightly thickened with fibrous tissue. However, this process does not involve the underlying parenchyma. There is a mild fatty metamorphosis and moderate degeneration involving the central portions of the lobules. In addition, yellowish-brown particles of bile crystals are scattered everywhere. (Since the tissue was poorly fixed, much of the latter process together with the fatty and degenerative changes may be post-mortem.)

Spleen.—No significant abnormality.

Adrenals.—No significant abnormality.

Related Studies

Wilfred D. David, Arthur H. Wolff, David Zinke and E. A. Tiboni

PULMONARY EMPHYSEMA STUDIES

It was heard often during the beginning of the study, that bronchial asthma was a common predisposing factor to the development of severe pulmonary failure during the smog. No scientific data were available to confirm this. However, it was early considered that any cardiac or respiratory disability that existed might predispose to more serious effects from any respiratory irritant. A cardiorespiratory system which was not in actual failure, but was near its limit of usable reserve might be pushed beyond its reserve limit and thus go into failure.

The most suitable way of testing this hypothesis would have been to take a series of persons with cardiorespiratory systems near failure and to make appropriate studies of them. However, this was not feasible for many obvious reasons. The most amenable way open to us was to observe the effect of the presence of pulmonary emphysema on the occurrence of illness during the smog.

Hurtado and others have shown that there is a close positive correlation between two ratios, namely, the ratio of the

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[14] The organs were kindly supplied by Dr. H. S. Levin who performed the autopsy.

[15] This material was prepared by Dr. Arthur J. Vorwald.

area of the expiratory lung silhouette to the inspiratory lung silhouette, and the ratio of the residual air to the total lung volume (*1*). It has also been shown that a high residual air is characteristic of obstructive pulmonary emphysema.

A series of duplicate chest roentgenograms were taken on a group of adult males, one roentgenogram taken during deep inspiration and the second on forced expiration. Both pictures were made on 14- by 17-inch films at the same target distance by the same operator. It was expected that calculating the "lung areas" in the two films and relating these, one to the other, would give the measure of the degree of pulmonary emphysema present.

The subjects chosen for this study were all male workers, apparently in good health, from a portion of the plant where it was known that no irritant aerosols existed because of the local plant operations. Of the 221 so X-rayed, 116 gave a history of having been ill with respiratory symptoms during the smog, and 105 gave a history of not having been ill during the smog. The group, therefore, provided its own control. The two groups had essentially the same age distribution.

Study of these roentgenograms was made by the Department of Physiology, Trudeau Foundation, Saranac Lake, N. Y. It was found that there was no significant difference between the test series and the control group with regard to the presence of pulmonary emphysema as determined by this method of study. It would appear, therefore, that emphysema did not play a significant role in the causation of symptoms due to exposure to the smog. This subject will be described in greater detail in a separate report by Dr. G. W. Wright, Trudeau Foundation.

INFLUENZA STUDIES[16]

Since the acute illness in the Donora area simulated a fleeting sweep of an influenza epidemic, it was necessary to study the outbreak to learn to what extent influenza may have been a part of that acute episode. The best method of making this study after the acute episode had subsided was to study the blood of persons of the community for significant titers of influenza antibodies.

As was described previously, a series of 516 persons in the area who had been ill during the smog were interviewed by physicians; of these persons, 223 volunteered to submit to venipuncture. The blood so obtained was analyzed for its influenza antibody titer. In addition, there was a group of 128 male adult workers in the steel plant who had allegedly not been ill during the acute episode, and these also submitted to venipuncture for the same purpose. All the blood samples were drawn three to four months after the October 1948, smog. All the analyses[17] were made by the haemagglutination-inhibition method of Salk (*2*). This test measures an immune response to infection or vaccination with the influenza organism and tests for a specific antibody identical to the complement-fixing antibody and the neutralizing or protective antibody; as such it is a measure of immune response to infection or vaccination with the influenza organism (*3*). By preparing serial dilutions of sera containing influenza antibodies it is possible to express quantitatively the highest dilution that completely inhibits agglutination (*2*, *4*). Analyses were so made for influenza B, A, and A′.

In response to infection or vaccination with the influenza organisms, antibodies are produced which reach a maximum titer in 10–14 days. The blood antibody titer begins to decline after 14–28 days and is usually at its base level after about 1 year (*5*). Noninfected and unvaccinated individuals generally have positive titers of less than 1:128. Titers of convalescent sera range generally between 1:256 and 1:2048 for a period of 3 to 4 months (*2*).

Table 22 shows the influenza B, A, and A′ antibody titer for the 351 persons tested in this study. These are divided into those who had allegedly been ill and those who had allegedly not been ill during the smog. In this table it can be seen that the incidence of positive serum, using the level of 1:256 dilution as significant, was very low. Thus, for those who had allegedly been ill the incidence of positive tests for such dilutions was 1.8 percent for influenza B, 3.1 percent for influenza A, and zero for influenza A′. Similarly, for those who had not been ill during the smog, the incidence of positive tests was zero for influenza B, 6.2 percent for influenza A, and 0.8 percent for influenza A′. There is evidence (*6–11*) that such an incidence can be expected at times remote from influenza epidemics.

It is therefore concluded from these data (confirmed by the autopsy findings) that an influenza outbreak was probably not the cause of the illness which occurred in the Donora area in October 1948.

ALLERGY AND SMOG ILLNESS

An attempt was made to obtain information on the relationship of a history of allergic manifestations to the incidence of illness due to the smog. Unfortunately, the data collected were too meager to warrant such an analysis, except for those data relating to the cases of bronchial asthma, already discussed, and to the examination of the blood smears for eosinophilia, sometimes considered as a possible indication of allergy. The results of the study of the eosinophile counts in the blood proved negative, since there was no significant difference in eosinophile percentages between a group who had been ill during the smog and a group that had not been ill. With regard to bronchial asthma it has already been shown that persons with this disease were especially prone to develop severe affection during the smog. This concept received further confirmation from a study of the hospitalized cases as well as those who died during and shortly after the smog.

BLOOD SPECTROPHOTOMETRY[18]

It is reasonable to expect that those air contaminants present during the smog might be present in the air of the community during other times. Samples of blood were therefore examined spectrophotometrically to determine whether or not changes in the blood could be found during the study period. The samples were diluted 10 times with distilled water, and were prepared for study by spectrophotometric methods. Appropriate dilutions of these specimens

[16] Participant: John P. Utz.

[17] All these analyses were made by the Laboratory of Infectious Diseases of the National Institutes of Health, Bethesda, Maryland.

[18] By F. H. Goldman and Ljubo Lulich.

TABLE 22.—*Study of influenza problem: Results of influenza antibody titer for 351 residents of the Donora area* [1]

Antibody titer	Persons given test for specified type of influenza								
	All persons			Persons ill during smog			Persons not ill during smog		
	Type B	Type A	Type A′	Type B	Type A	Type A′	Type B	Type A	Type A′
	Percent of persons								
Total	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
Less than 32	61. 3	57. 6	55. 3	50. 2	53. 4	54. 3	80. 5	64. 8	57. 0
32	23. 9	19. 9	29. 9	30. 9	24. 7	32. 3	11. 7	11. 7	25. 8
64	10. 6	12. 2	12. 2	13. 5	12. 5	12. 5	5. 5	11. 7	11. 7
128	3. 1	6. 0	2. 3	3. 6	6. 3	. 9	2. 3	5. 5	4. 7
256 and over	1. 1	4. 3	. 3	1. 8	3. 1	0	0	6. 3	. 8
256	1. 1	2. 9	0. 3	1. 8	1. 8	0	0	4. 7	0. 8
512	0	1. 1	0	0	. 9	0	0	1. 6	0
1,024	0	. 3	0	0	. 4	0	0	0	0
	Number of persons								
Total	351	351	351	223	223	223	128	128	128
Less than 32	215	202	194	112	119	121	103	83	73
32	84	70	105	69	55	72	15	15	33
64	37	43	43	30	28	28	7	15	15
128	11	21	8	8	14	2	3	7	6
256 and over	4	15	1	4	7	0	0	8	1
256	4	10	1	4	4	0	0	6	1
512	0	4	0	0	2	0	0	2	0
1,024	0	1	0	0	1	0	0	0	0

[1] Analyses made by the haemagglutination-inhibition method of Salk (*2*). All blood samples were drawn 3 to 4 months after the smog episode.

were made in the laboratory, and analyses were performed using a Beckman spectrophotometer after the material was buffered to pH of 6.94. A series of 114 samples of blood specimens from persons living in Donora who had been ill during the smog were studied in this manner. The absorption curves showed no evidence of any abnormal components (*12*), such as methaemoglobin, sulfhaemoglobin, and carbon monoxide haemoglobin.

For these reasons it is apparent that during the period of study, no such air contaminants were present to the extent that they would cause such blood changes.

STUDY OF DOMESTIC ANIMALS

Since the smog episode in the Donora area had an effect upon the health of humans, it would be expected that domestic animals might also have been affected. A trained veterinary physician was assigned to study this phase of the problem.

It was anticipated that a study of the veterinary aspects of the problem might yield information of value in four directions, namely: (1) Assist in providing data on morbidity and mortality which might be useful in clarifying the clinical syndrome as observed in humans; (2) assist in providing data of value in determining the probable etiologic substance (or factor) to account for the human illnesses; (3) signify the economic effect on livestock caused by air pollution in the community; and (4) aid in the selection of an animal species suitable for use in future laboratory experimentation of the study of biological effects of air pollution.

Methods

The sources of veterinary information in the relatively urban area were, in the main, twofold: (1) The community survey made by nurses of the study team, and (2) persons in the community who believed they had information of significance. It is apparent that morbidity and mortality rates could be derived only from the first source, although the latter source, that is, persons who volunteered information, could provide valuable clinical data. For many reasons it was not possible to obtain appropriate data in another area to serve as a control.

Collateral data were collected through conferences with three local veterinarians, technicians in a local dairy cattle breeding association, the county agents (of the two counties involved in the study) of the United States Department of Agriculture, three local poultry dealers, and a slaughterhouse operator. These persons were questioned concerning any animals which might have been in their charge during the period of the smog or thereafter. Four retail milk plants in the area were visited to determine if there were any record of decline in milk production, during or shortly after the smog, in those dairy herds in the Donora vicinity.

When the nurses visited households selected for the survey, they made specific inquiry as to the presence of domestic animals on the premises. If animals were kept or had been kept on the premises, inquiry was made as to the occurrence of illness among those animals during the period of the October 1948 smog. The veterinarian then visited each of the households in which animal illness was reported and, by the use of

a form (fig. 50) developed for this purpose recorded data on the illness.

Since the collection of data by the nurses occurred two to four months after the acute episode had subsided, and since the veterinary physician visited the homes subsequent to the nurses, it is well to keep in mind the lapse of time involved. Moreover, it was felt that the tendency of humans to personify their animal pets would further influence the data. It is not possible to evaluate the extent to which these influences modified the final data on animal illness as collected.

Because the survey of households was limited to the urban area, little data on livestock were obtained through that source. It was therefore necessary to visit the immediately surrounding rural area. A random sampling of farms was

DONORA STUDY

HISTORY OF ANIMAL ILLNESS

Animal Case No. ________

Name of owner ______________________ Address ______________________

Household No ____________ Telephone No ____________ Date ____________

SMOG SYMPTOMS

Onset ____________ Respiration ____________ Coughing ____________

Sneezing ____________ Nasal discharge ____________ Eyes ____________

Attitude ____________ Appetite ____________ Nausea ____________

Vomiting ____________ Stools ____________

Other symptoms ______________________

____

____

Length of symptoms ______________________

Veterinary care ______________________

ANIMAL HISTORY

Species ______________________ Sex _____ Age _____ Weight ________

Animal health prior to smog ______________________

____

____

Veterinary care prior to smog ______________________

____

____

OTHER ANIMALS ON PREMISES (Species, age, sex)

____

____

____

REMARKS

____

____

____

____

____

____

____

Informant ______________________ Investigator ______________________

FIGURE 50.—*Form used in obtaining history of animal illness.*

made within a 3-mile easterly radius of one portion of the plant. In all, about one-fifth of the farmers in the area were interviewed about their animals. In addition, the veterinarian inspected the animals for evidence of disease.

At the time the veterinary physician was making his observations and collecting data on the possible acute effects of the smog, he also collected certain information and specimens for laboratory examination which it was thought might be useful for the purpose of evaluating the effects of continuous residence in the community on the health of animals and possibly humans. This latter phase of the veterinarian's contribution to the study is considered in a later section dealing with fluoride effects.

Results

The conference held with local veterinarians, county agents, technicians of the local dairy cattle breeding association, poultry dealers, and slaughter-house officials, revealed that they had observed no unusual incidence of illness among their animal charges during the smog. According to the records of four retail milk plants, there was no significant drop in milk production during the smog or during the period after the smog among dairy herds in the surveyed area.

The main body of data collected was from the community survey. Table 23 shows the distribution of domestic animals

TABLE 23.—*Estimated smog morbidity, and mortality rates for domestic animals, by species; based on data reported for 1,208 households covered in community survey*

Animal species	Number of households with one or more animals of given species	Estimated number of animals	Animals affected by smog		Animal deaths attributed to smog	
			Number	Percent	Number	Percent
Dog	229	245	38	15. 5	10	4. 1
Cat	131	165	12	7. 3	3	1. 8
Fowl	43	550	60	10. 9	7	1. 3
Canary	17	20	4	20. 0	2	10. 0
Rabbit	7	(1)	20	(1)	2	(1)
Pigeon	4	25	0	0	0	0

1 Data on estimated number of rabbits are not available.

by species as well as the incidence of illness and death among them. Omitted from this table are a few small reptiles and fish kept as household pets. Also excluded are two cows and one parakeet which showed no smog effects.

Effects on dogs.—The manifestations of smog effects varied among the animal species. It will be observed from table 23, that 38 dogs (15.5 percent) were said to have been made ill by the smog. Ten of the animals (26.3 percent of those ill) died. In addition to the ill dogs reported in the community survey, nine ill dogs were reported from other sources. Clinical data on these nine cases are included in table 24 only.

The symptoms described as having occurred among the sick dogs were divided into three groups, namely: "Change in attitude," respiratory system symptoms, and digestive system symptoms. "Change in attitude" refers primarily to anorexia with or without lassitude or lethargy. Such a condition was reported in 36 cases. Respiratory system symptoms included cough (21 cases), sneezing (7 cases), dyspnoea,

TABLE 24.—*Fatality rates based on the experience of 47 dogs* [1] *reported ill* [2] *during the smog, and classified according to various factors*

Factor	Fatality rate; percent of ill dogs that died	Number of dogs reported ill during the smog	Number of ill dogs that died during or after the smog
Age in years:			
Under 1	83. 3	12	10
1–5	0	10	0
6–10	10. 0	10	1
11 and over	50. 0	4	2
Unknown	0	11	0
Day of onset of illness:			
S-day	66. 7	3	2
Day number 1	33. 3	3	1
Day number 2	23. 1	13	3
Day number 3	50. 0	6	3
Day number 4	0	1	0
Unknown	19. 1	21	4
Duration of illness in days:			
1–7	28. 0	25	7
8–14	100. 0	3	3
15–60	66. 7	3	2
Unknown	6. 3	16	1
Symptoms:			
Change in attitude only	0	8	0
Change in attitude with 1 or more other symptoms	39. 3	28	11
Respiratory only	0	4	0
Respiratory with 1 or more other symptoms	37. 0	27	10
Digestive with 1 or more other symptoms	42. 1	19	8
Other and ill-defined symptoms only	42. 9	7	3
Total	27. 7	47	13

1 The 47 dogs include 38 reported ill in 1,208 households covered in the community survey, and 9 other dogs reported by their owners as ill during the smog.
2 "Ill" includes change in attitude, respiratory, digestive, other, or ill-defined symptoms attributed to the smog.

(8 cases), and nasal discharge (3 cases). Evidence of eye irritation was included in the category of respiratory symptoms. "Redness" of the bulbar conjunctivae with or without epiphora was reported in 12 cases. Digestive system symptoms included retching, with or without vomiting (13 cases), and diarrhea (2 cases).

It is observed in table 24 that, when dogs with known ages are considered, the greatest percent that died was reported for dogs under one year of age, and those 11 years of age and older. Of the 12 dogs which were under 1 year of age, 10 died. Simarly, of the 4 dogs which were 11 years or older, two died. The day illness began was recorded for 26 dogs who became ill during the smog. Day No. 2 accounted for 13, and day No. 3 for 6. Of the 9 dogs that died and for which the day of death was obtainable, 3 died on day No. 2 and 3 on day No. 3.

It was difficult to elicit information on the duration of illness of the dogs. Of the 31 dogs for which this information was obtained, the median duration was 3.5 days. Eighteen dogs were ill for from 1 to 6 days, 7 for approximately 1 week, 3 for approximately 2 weeks, and 3 for approximately 1 to 2 months. It was observed that except for those cases that ended fatally, the canine disease was in the main mild and transient in nature.

Effects on other animals.—Of the 131 householders who informed us that they had cats on their premises (a total of

approximately 165 cats), 12 had cats who became ill during the smog and in 3 instances the cats died. Clinical effects in these animals were quite similar to those described for dogs. Of the cats that died, one was 6 months old; one 2 years old; and one 8 years old.

There were 43 households, which kept approximately 550 chickens or turkeys on their property. Only two of the households indicated that fowl were affected by the smog. Among one flock of 10 pullets in the Borough of Donora "sniffles," anorexia, and droopiness were noticed, but there were no deaths. In the other flock in Webster, 50 chickens were said to have been ill with obscure symptoms, and 7 died within 48 hours of onset of illness. However, it should be noted that the three poultry dealers in Donora who had live chickens on their premises during the smog observed no ill effects among them. In addition to the two households in the urban area reporting illness among fowl, four farmers alleged that their flocks had been affected during the smog. The combined mortality was high—probably over 40 percent among the affected birds. Approximately 250 birds were said to have died. With the meager case histories that were available, the symptomatology generally resembled one of the infectious respiratory diseases common to fowl.

Of 17 householders who indicated that they kept canaries, four offered the information that the birds became ill during the smog and that in two instances they died. Clinical data on the illness among the canaries were not obtainable. In addition to the information obtained through the household survey, other information that came to our attention signified that canaries had allegedly died from "smoglike conditions" in the community during the periods prior to the October 1948 smog episode.

Of the 7 households where rabbits were kept, only 1 reported illness. Here there were 20 animals, most of which became ill on day No. 1, and the illness, which consisted of anorexia, lethargy, and "dark" discoloration around the mouth and nose, lasted about 1 week. None of the rabbits was over 4 months of age. Two fatalities occurred in this group.

Of 22 farms visited in the rural area, 13 had dairy cattle, a total of approximately 250 head. Of these 13 dairy farmers, 3 claimed that their cattle had been affected with cough during the smog. On one farm, five cases of calf pneumonia were said to have occurred immediately after the smog. There was no evidence of a significant decrease in milk production on the farms during the smog or thereafter.

Among the 22 farms visited there were 8 horses, 12 sheep, and 30 swine. None of these was alleged to have been ill during the smog.

Discussion

From the data presented it is apparent that the domestic animal population was affected by the smog to the extent that an appreciable number became ill and that some died. The attack rate appeared to vary with the animal species, dogs appearing to have been most susceptible, both as to morbidity and mortality. However, it is well known that dogs in the age group most involved, that is, one year of age and younger, are highly susceptible to distemper, especially at the season of the year in which the smog occurred (*13, 14, 15*). The data available were not adequate to rule out distemper as a factor in contributing to the observed sickness and death rates.

The illness as observed among the animals appeared, in general, to be a type of general debility with most of the symptoms being referable to an inhaled irritant material with respiratory infection as a sequel (*16*). The information is, in our opinion, inadequate to give any further leads as to the specific causative agent or agents in the air which produced those effects.

Conclusions

1. The syndrome as observed among animals was of a nature which could be attributed to an irritant of the exposed mucous membranes and, more specifically, the respiratory tract.
2. Among the domestic animals for which information was available, attack rate for dogs was 15.5 percent. The fatality rate among the affected dogs was 26.3 percent.
3. The role which distemper played in the high incidence of morbidity and mortality among the dog population appeared to be considerable, but there was no way open to us to measure this role.
4. The economic loss due to smog effects on farm animals was minimal.

CONDITIONS OF HOUSING[19]

An evaluation of housing was conducted to provide information on the descriptive characteristics, quality, and important deficiencies of dwellings in the Donora area, in an attempt to ascertain possible relationships between housing conditions, and illnesses and deaths occurring at the time of the smog. Weather-tightness and general state of repair of dwellings were considered of special importance, but a full range of factors known to affect housing quality was examined as well.

The Sample

A general housing sample of 5.56 percent of all families in the area was established by selecting one-sixth of the families chosen for interviews by the nurses. Of the total of 241 dwellings thus selected, 220 were located in Donora, and 21 in Webster and Carroll Township. In addition, 20 dwellings which had served as residences of persons deceased during or shortly after the smog were inspected.

For dwellings in the general sample, information on the presence in the household of mild, moderate, or severe affection from the smog was obtained from the collected medical data. This information was used to determine four classes of dwellings, namely: (1) Dwellings in which no occupant was affected; (2) dwellings in which at least one occupant was mildly affected; (3) dwellings in which at least one occupant was moderately affected; and (4) dwellings in which at least one occupant was severely affected. It will be observed that the four classes are not mutually exclusive since a dwelling in which both moderate and severe affection occurred, for example, was counted in both classes 3 and 4. The number of sampled dwellings in each of the four classes was 69, 82, 92, and 77 respectively.

[19] Participants: F. S. Kent, and Rosedith Sitgreaves. A more detailed report will appear elsewhere.

Method of Evaluation

The housing evaluation was conducted with the use of the American Public Health Association method for measuring the quality of housing (*17*). Appraisal items included measurements of the deficiencies of the following aspects of the dwelling: (1) *Facilities*, such as toilet, bath, kitchen, heating, lighting, water supply, sewage disposal, and safety of escape for use in emergency; (2) *maintenance*, such as sanitary condition and infestation, as well as state of repair; and (3) *occupancy* according to various degrees of crowding. Graded penalty scores were assigned to conditions which failed to meet a reasonably contemporary housing standard.

General Findings

Findings of the evaluation revealed that housing conditions in the Donora area compared reasonably well with conditions in other urban communities of similar size in the United States. On the basis of the total penalty scores, approximately two-thirds of the dwellings were rated as having good to excellent over-all conditions of housing. By an auxiliary rating system, almost half of the dwellings were considered essentially satisfactory in that they had no basic deficiency. In general, conditions in Webster and Carroll Township were less satisfactory than in the area as a whole.

Housing and Affection From Smog

An examination of the quality of housing provided by dwellings in each of the four classes defined above revealed that the percent of dwellings rated "good to excellent" decreased concurrently with increasing severity of affection. This percentage ranged from 68 percent of dwellings in which no affection occurred, to 59 percent of dwellings in which at least one member was severely affected. Only 30 percent of the dwellings in which deaths occurred were classified as providing "good to excellent" conditions of housing.

A combination of scores given for facilities and deterioration provided a composite index of the physical quality of a dwelling and its ability to resist infiltration of the outside atmosphere. Combined scores of 0–29 penalty points were considered to represent dwellings of good physical quality, relatively well able to withstand atmospheric infiltration. At the other end of the scale, scores of more than 60 penalty points were regarded as representing dwellings whose physical quality and ability to withstand atmospheric infiltration were relatively poor. Approximately half of the dwellings in each of the four classes had scores of less than 30 penalty points. However, it is worth noting that with increasing severity of affection, the percent of dwellings with scores of 60 penalty points or more increased from 18 to 32 percent. Thirteen, or 65 percent, of the 20 dwellings in which deaths occurred had scores of 60 penalty points or more.

On the basis of these data, therefore, there appears to be some relationship between severity of affection and certain of the characteristics of housing quality.

COMMUNITY SANITATION[20]

Since it is known that certain types of epidemic disease may have their origin in water supply, food intake, and mode of sewage disposal, a careful study was made of these factors in the Donora area by sanitary engineers, trained in the techniques of such investigations.

Detailed studies were made of the water supply, sewage disposal, garbage disposal, and milk and food sanitation. The findings revealed defects in sanitation but no evidence that these factors could be linked to the acute episode in the Donora area.

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[20] By H. B. Robinson and F. B. Taylor. This is a condensation of the original report on community sanitation.

LONG-TERM EFFECTS

It was early recognized that while making a study of the acute episode, it would be useful to collect data on the effects of continued-living in the community. Further, some of the data so collected might be useful in giving leads as to the causative agent, or condition, which might have accounted for the acute episode. Finally, it is logical to expect that if air pollutants in a given community can account for an acute episode, those same pollutants would be present in the air of the community to a lesser degree during other times. As a matter of fact, information came to us, as the study progressed, that the air in the community was quite often irritant to some of the residents. It was for these reasons that efforts were made to obtain information which could be interpreted as effects of air pollutants on health as a result of continuous living in the community.

Special studies were thus made of morbidity records available for certain of the industrially employed. The record forms used in the household canvass and by the physicians included questions on general health status with emphasis on respiratory tract disease. Selected groups were examined for study of effects on their oral structures. And finally, studies were made of available mortality records of the Donora area.

Oral Structures [1]

Francis J. Walters

METHODS

Atmospheric pollution by fluoride and aerosols in various concentrations may leave its mark on both human and animal bodies living in the area. Evidence of fluoride exposure may appear in the bone, in the teeth, and in the urine (*1–8*). Acid aerosols are known to cause acute symptoms of haemorrhagic gingivitis and chronic symptoms of dental erosion (*9–10*).

Accordingly, a study was made to ascertain if fluoride or acid aerosol contaminants were present in sufficiently high concentration, first, to cause harmful effects on the oral structures and, second, to produce any systemic manifestations.

Oral examinations were performed to provide information on the effects of acid aerosols on the oral structures, and to assist in defining the role which fluorides may have played in the condition of the teeth. Since the latter objective might lead us into having a higher degree of suspicion that fluoride may have contributed to acute illness during the smog, it was necessary to have data to affirm or negate such a suspicion. The veterinary physician of the study team collaborated with the dentists in obtaining information on this latter point.

Oral examinations, beginning 3 months after the smog and continuing for 1 month, were made by one dentist who limited his study to the observations which could be made with the use of a Castle light, type 1, and a No. 6 mouth mirror.

All pathologic conditions and abnormalities of the lips, mucous membranes, gingivae, teeth, tongue, palate, uvula, and velum were noted and entered on forms developed for the study. (See fig. 51.) Roentgenograms were not employed. The persons examined were limited for convenience to two groups, namely, male adults and male school children. Both groups were examined to determine the possible effects upon the oral structures of fluoride and of acid aerosol contaminants in the general atmosphere.

Examination of Male Adults

With the cooperation of plant management, male employees were asked to volunteer for an oral examination. The facilities of the medical department of the local steel plant were placed at the disposal of the examiner. This plan expedited the collection of the desired data for male adults. Those invited to participate were from sections of the plant where it was known that no irritant aerosols were present in the plant environment due to the departmental processes. The workers were thus considered to be representative of adults of the community. The 262 men examined were considered adequately representative.

Examination of School Children

The primary purpose of the examination of the school children was to determine whether or not acid aerosols affected the oral structures and whether or not fluorides, from any source, were present in sufficient quantities to have caused abnormal development of the teeth or altered the rate of caries attack. With parental permission and the cooperation of the school authorities, 375 male students between the ages of 12 and 20 from the Donora Junior and Senior High Schools were examined.

In addition, students from the Webster Consolidated School were also examined. Because of the incomplete permanent dentition of school children below the age of 12, only the junior and senior high-school students were examined for abnormal dental development and dental caries attack rate.

The first-aid rooms of the junior and senior high schools were placed at the disposal of the examiner. With the help

[1] Participants: F. J. McClure and Walter F. Hoffmann.

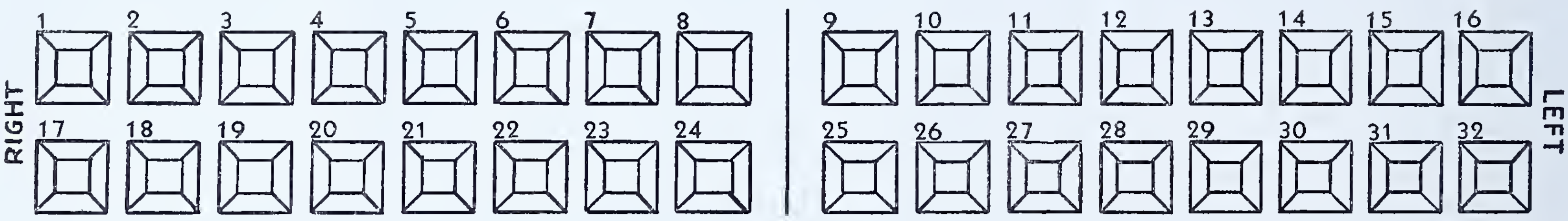
DONORA STUDY

ORAL EXAMINATION

Date	Household No.	Case No.

Name	Color	Sex	Age	Present Occupation	Time Yrs.

Address	Continuous Residence Yes No	Urine Specimen Y. N.



Calculus 0 1 2 3 4	Periclasia 0 1 2 3 4	Type of Calculus 1 2 3	Enamel

Gingival Cavities	Other Cavities	Photo Number Subject

REMARKS

------	LIPS Normal Abnormal	------	GLANDS Normal Abnormal
------	Inflammation L 1 G L 2 G L 3 G	------	Other Conditions
------	Fissure		
------	Keratosis L 1 G L 2 G L 3 G L 4 G	------	TONGUE Normal Abnormal
------	Other Conditions	------	Fissure
		------	Keratosis L 1 G L 2 G L 3 G L 4 G
------	GINGIVAE RIDGES Normal Abnormal	------	Varicosity
------	Gingivitis L 1 G L 2 G L 3 G	------	Other Conditions
------	Color Change		
------	Tissue Tonus	------	MANDIBLE Normal Abnormal
------	Keratosis L 1 G L 2 G L 3 G L 4 G	------	Exostosis
------	Other Conditions	------	Other Conditions
------	ORAL MUCOSA	------	NEOPLASM Present Absent
------	Inflammation L 1 G L 2 G L 3 G		
------	Keratosis L 1 G L 2 G L 3 G L 4 G	------	TEETH AND SUPPORTING STRUCTURES
------	Other Conditions	------	No. of Teeth Missing
		------	No. of Teeth Replaced
------	PALATE Normal Abnormal	------	No. of Teeth Carious
------	Inflammation L 1 G L 2 G L 3 G	------	No. of Teeth Restored
------	Keratosis L 1 G L 2 G L 3 G L 4 G	------	Bridges
------	Exostosis	------	Dentures
------	Other Conditions		
			DENTAL NEED
------	VELUM Normal Abnormal		
------	Inflammation L 1 G L 2 G L 3 G	------	No. of Teeth Requiring Filling
------	Other Conditions	------	No. of Extractions Indicated
		------	No. of Bridges Indicated
------	UVULA Normal Abnormal	------	Partial Dentures Upper Lower
------	Inflammation L 1 G L 2 G L 3 G	------	Full Dentures Upper Lower
------	Other Conditions	------	Prophylaxis

FIGURE 51.—*Form used for recording data on condition of oral structures.* (*Reverse of form carried Water History.*)

of the school nurse and school officials, examinations were performed by the same methods and with the same equipment employed in the examination of the adults. All abnormalities were similarly noted and entered. The findings of only those students between 13 and 17 years of age were considered. Since the number available for examination under 13 years of age and over 17 years of age was too small to be significant, they were not considered in the analysis. Similarly, because of the small number of students examined in the Webster school below and above the age of 13, only the 29 in the 13-year age group were given consideration. A complete chronological history of residence was obtained for each child. The children were then classified into two groups—those who had resided continuously in the Donora area since birth and those who had not.

Chemical Studies

As already mentioned, pertinent data were collected to assist in the interpretation of oral findings relative to fluoride effects. Thus, samples of the communal drinking water used by the Donora residents were collected and analyzed for fluoride content.

The residents of Webster, having no communal supply, obtained their water from three sources, namely, drilled wells, cisterns, and springs. A representative sample of each was collected and similarly analyzed for fluoride content.

Human bone specimens from rib sections of three autopsied bodies of persons of long-time residence in the area who died allegedly as a result of smog were analyzed for their fluoride content. Urine samples were collected from the adults, and junior and senior high-school students, who had a history of residence in Donora and were using the communal water supply. Fifteen ml. from each urine specimen were pooled in accordance with age groups to a quantity of 300 ml. and to this were added 3 ml. of toluene as a preservative (4). The pooled sample was then analyzed for its fluoride content.[2]

The veterinarian obtained bone specimens of domestic animals. The specimens included mandible, rib, vertebrae, scapula, and femur obtained from a 3- to 5-month-old calf, an 18-month-old heifer, and a 2-year-old bull, as well as specimens from an emaciated pullet. The veterinarian also made clinical observations for evidences of fluoride effect by inspection of 8 horses, 250 cattle, 30 swine, and 12 sheep. This information was combined with the other data as evidence of the presence or absence of fluoride effects.

FLUORIDE EFFECTS

Teeth of School Children

Because of the heterogeneous nature of the residence of the adults during their tooth development period, attention in this study was centered on school children.

A peculiar type of deformity of the enamel of the teeth known as mottled enamel is classified according to severity from "questionable" to "severe" (*11*). It is a developmental disturbance resulting in poor calcification of the enamel and dentin. Dental fluorosis or mottled enamel varies directly, in extent and severity, with the amount of fluoride ingested during the period of tooth development. No case of mottled enamel was observed among the 427 school children from the Donora and Webster Junior and Senior High Schools.

In addition to dental fluorosis caused by fluoride intoxication, fluoride has been frequently referred to as a caries-inhibiting agent. This concept has been well substantiated (*6, 12–17*). It may be said, therefore, that the caries experience rate of a group of children could be related to fluoride exposures from the various sources. It was believed that the DMF,[3] or caries experience rate, of the children examined from the Donora and Webster schools could be compared with a similar group from other areas to determine what effect fluoride from any of the known sources may have had in altering the DMF rate. Four Illinois cities, from a study conducted by Dean, et al. (*12, 13*), were selected for this purpose. These cities presented a wide range of fluoride content in the communal water supply and a wide range of caries experience. Since the Donora study included no 12-year old children, only the 13- and 14-year-old groups of the Illinois cities were considered for comparison.

Of the 427 school children examined, 375 were from Donora and 52 from Webster. Eliminating from our consideration, for reasons already given, those children below 13 and those over 17 years of age, there remained a total of 334 from Donora and 29 from Webster whose caries experience rate by age is presented in table 25. Of the 334 from Donora Borough, it was found that 247 gave a history of continuous residence since birth and 87 a noncontinuous residence. The two groups were first considered separately in calculating the

TABLE 25.—*Average number of DMF teeth [1] per 100 children, by age; experience of 29 school children in Webster and 334 school children in Donora Borough*

Residence, and age in years at last birthday	Average number of DMF teeth per 100 children	Number of DMF teeth	Number of children examined
Webster, age 13	503	146	29
Donora, ages 13–17	724	2, 418	334
13	570	319	56
14	710	433	61
15	659	481	73
16	753	497	66
17	882	688	78

[1] DMF teeth include (D) teeth decayed, (M) teeth missing or indicated for extraction, (F) teeth filled. A tooth is counted once only.

[2] The fluoride determinations for all biological materials were made by the National Institute of Dental Research.

[3] The amount of dental caries experience observed in the permanent teeth of a particular age group may be expressed in terms of the number of teeth with untreated dental caries, the number of extracted teeth (including teeth indicated for extraction), and the number of teeth filled. All three findings (decayed, missing or filled) may be considered separately or may be combined into a single rate known as the DMF rate. In calculating this rate each item is mutually exclusive with respect to any other tooth. A tooth containing both a filled and one or more carious lesions is counted as a filled tooth. All teeth indicated for extraction are considered as missing teeth. Thus, the same tooth may not be counted more than once. The unit of measurement is the individual tooth, not the tooth surface. In each mouth the total number of teeth given consideration is 28 (*18*).

To illustrate, in the compilation of the data it was found that the 247 children from Donora, with continuous residence in Donora since birth, had 617 decayed, 404 missing, and 775 filled teeth. A total DMF for the 247 children was 1,796 or a DMF rate of 727 per 100 children. The 87 noncontinuous resident children had 227 decayed, 139 missing, and 265 filled teeth or a DMF rate of 725 per 100 children.

DMF rate. It was found that those of continuous residence presented a rate of 727 per 100 children and those of non-continuous residence 725. Since no significant difference existed between the DMF rates of the two groups, both were combined for purpose of comparison with the control study. Webster and Donora data are presented with data from the control cities in table 26, and graphically in figure 52.

TABLE 26.—*Average number of DMF teeth*[1] *per 100 children ages 13 and 14, in relation to fluorine in the drinking water; experience of school children in Donora Borough, and Webster in comparison with children in four Illinois cities*[2]

Location	Fluorine in water (ppm)	Average number of DMF teeth per 100 children of specified age (last birthday)		Number of children examined
		13	14	
Oak Park	0	696	907	208
Evanston	0	676	793	174
DONORA BOROUGH	.1	570	710	117
WEBSTER	[3] .3	503	(4)	29
Elgin	.5	449	529	241
Joliet	1.3	321	354	320

[1] DMF teeth include (D) teeth decayed, (M) teeth missing or indicated for extraction, (F) teeth filled. A tooth is counted once only.
[2] Data for four Illinois cities are from reference *13*, tables 4, 5, and 13.
[3] The Webster water supply was from 3 sources; deep well, 0.4 ppm; cistern, 0.3 ppm; spring water, 0.2 ppm. Therefore, an average of 0.3 ppm is used as the fluoride content for this group.
[4] The number of children examined is too small for consideration.

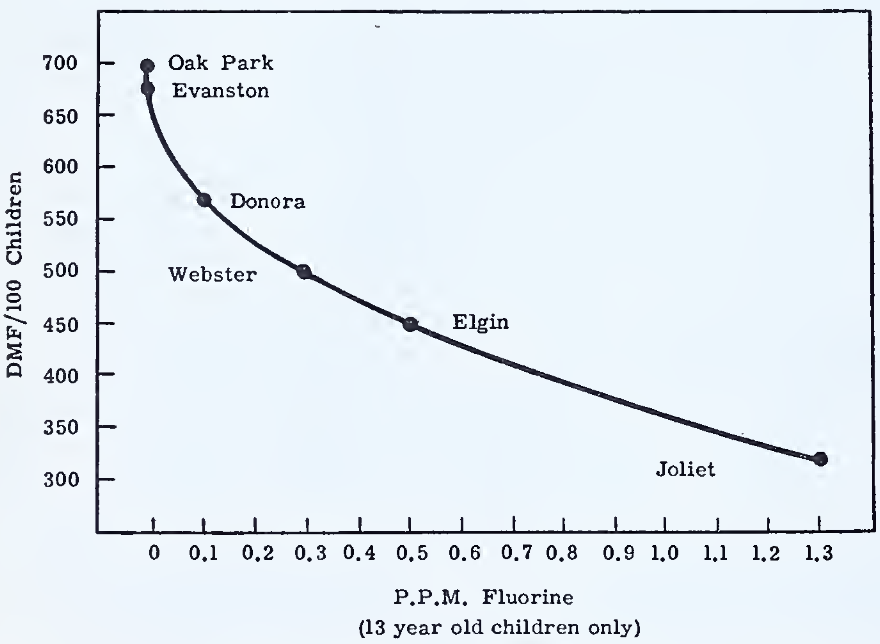


FIGURE 52.—*Average number of DMF teeth per 100 children age 13, in relation to fluoride in drinking water; experience of school children in Webster, and Donora Borough in comparison with children in four Illinois cities.*

Dean (*12*) states "that the inhibitory agent is the fluoride content of the water supply seems highly probable. An inspection of the range of different fluoride concentrations discloses an inverse relation in general between the amount of dental caries and fluoride concentration of the common water supply."

The fluoride content of water from the four Illinois cities varied from 0.0 to 1.3 ppm, with a caries experience rate ranging from 696 to 321 per 100 for the 13-year-old group, and from 907 to 354 per 100 for the 14-year-old group, denoting an inverse relationship in the variation of caries experience rate and fluoride content of the communal water supply. The Donora Borough group, compared to the four cities in Dean's report, falls within the pattern of inverse variation of caries experience rate and the fluoride content of the communal water supplies. The fluoride content of the communal water of Donora is found to be 0.1 ppm, with a caries experience rate of 570 per 100 for the 13-year-old group, and 710 per 100 for the 14-year-old group. Should there be a fluoride intake other than the 0.1 ppm, obtained from the common water supply for the Donora group, it would be reasonable to assume that the caries experience rate would be lower than was found.

With due regard for the small number, it is of interest to note in figure 52 that the findings among the group of 13-year-old children from Webster also fall within the pattern of inverse variation. Since the inverse variation is undisturbed when relating the Donora and Webster groups with the Illinois groups, it appears that the fluoride intake from sources other than the common water supply was not sufficiently high to alter this variation.

Fluoride Content of Urine

The 19 pooled specimens of urine collected from the Donora adults and children were analyzed for fluoride content. Each pool represented a sample from approximately 15 different persons of the same age group. The fluoride content for the 19 pools ranged from 0.14 to 0.51 ppm, with an average of 0.31 ppm. Since no significant differences of urinary fluoride content appeared among the various age groups, the average for the 19 pools was used as the fluoride content of the Donora group. Six of the 13 areas studied by McClure and Kinser were selected for controls (*4*). They were selected because of their broad distribution over a wide geographical area and because their drinking water presented a wide range of fluoride content with a similar wide range of urinary fluoride content. These data, with the Donora data, are presented in table 27.

Unusual amounts of fluoride intake either by ingestion or inhalation will be partially stored in the skeletal system

TABLE 27.—*Fluorine content of urine in relation to fluorine in drinking water; analyses of 19 pooled specimens from male adults and male school children in Donora, Pa., in comparison with specimens from males in 6 other locations*[1]

Location and occupation of males examined	Number of pooled specimens	Fluorine in water (ppm)	Fluorine in urine (ppm)
Little Rock, Ark.: High school boys, ages 15–18	26	0	0.3
Manchester, N. H.: Military selectees in induction center	174	0	.3
DONORA.: Male adults and male school children	19	.1	.3
Quincy, Ill.: High school boys, ages 15–17	85	.1	.3
Aurora, Ill.: High school boys, ages 15–17	173	1.0	.9
Lubbock, Tex.: Military personnel stationed at gliderfield	16	2.0	2.0
Lubbock, Tex.: Military personnel stationed at airfield	50	5.1	4.0

[1] Data for location other than Donora are from reference *4*. P. 1583.

and partially excreted (*4, 19–21*). It is reported that the urinary fluoride excretion parallels closely the level of intake of the preceding 24 to 72 hours (*4*). Within certain limits the amount of fluoride excreted indicates the amount of retention by the body. It will be noted from the foregoing table that the fluoride content of the communal drinking water for the Donora group and the control group range from 0.0 to 5.1 ppm, with a fluoride content of urine ranging from 0.3 to 4.0 ppm. Moreover, as shown in figure 53, there is a

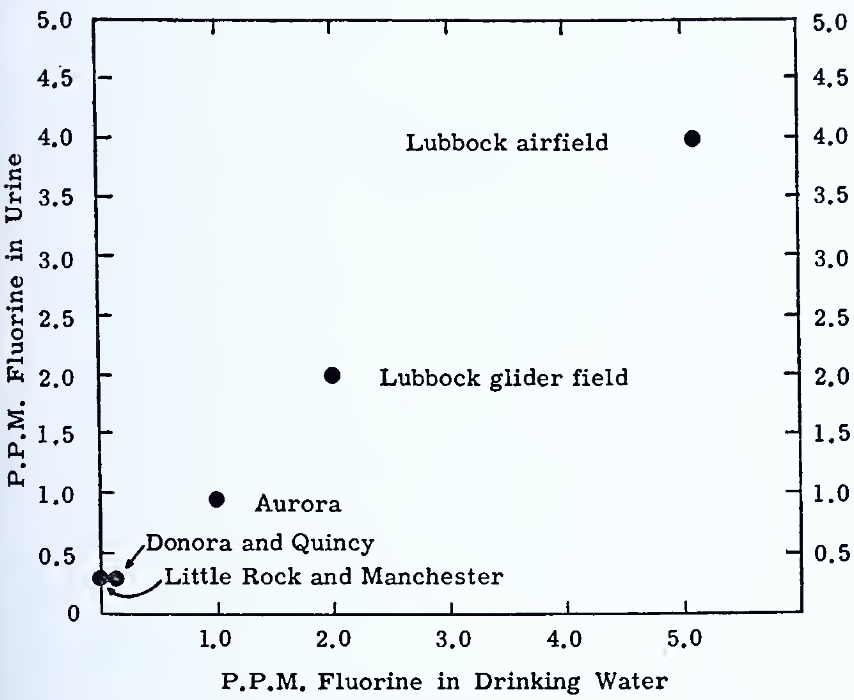


FIGURE 53.—*Fluoride content of urine in relation to fluoride in drinking water; analyses of 19 pooled specimens for male adults and male school children in Donora in comparison with specimens from males in 6 other locations.*

direct relationship between the fluoride content of the communal water and the amount of fluoride excreted in the urine. The fluoride content of the urine of the Donora group is the same as that found in Little Rock, Manchester, and Quincy, which are considered to be fluoride-free areas. In view of the foregoing, we are led to conclude that fluoride exposures for the Donora group, from sources other than the water supply, were not present in sufficient quantities to cause an abnormal increase in fluoride content of the urine.

Fluoride Content of Bones

In excessive amounts from the industrial atmosphere, fluoride will give rise to thickening of bones and ossification of the ligaments (*7, 22, 23*). It is stated that the abnormal fluoride content in the bone is an index of fluoride intoxication (*7, 22–24*). Machle and Scott (*24*) describe abnormal storage of fluoride in the bones of rabbits exposed to sublethal concentrations of hydrogen fluoride. Toxic levels of fluoride in forage are deemed attributable to direct contamination from the atmosphere (*25, 26*). Farm animals, feeding on fluoride-contaminated grass and hay will yield high urinary fluoride values 8 months after discontinuance of the ingestion of such fluoride-contaminated food (*7*). Similarly, the skeletal system will retain fluoride subsequent to the discontinuance of such exposure (*7, 27*). The length of time fluoride is retained in the skeletal system after cessation of exposure may be altered by the amount and the duration of the exposure.

The fluoride content of the normal human rib from a fluoride-free area is reported by Glock, Lowater, and Murray (*27*) as ranging from 0.2 to 3.0 percent fluoride in fat-free bone with an increase directly proportional to age. The fluoride content of the three human rib specimens from Donora ranges from 0.0174 to 0.1408 percent in fluoride fat-free bone.

The normal fluoride content of the cattle bone used by Chang et al. (*8*) as a control is reported to range from 0.0569 to 0.600 percent. The cattle bones collected in the Donora area range from 0.0261 to 0.0657 percent fluoride. The Armstrong modification of the Willard-Winter technique (*28*) used for the determination of fluoride in bone was the same method utilized by Chang, Glock, and their co-workers.

These limited data indicate that the fluoride intake of the human, as well as cattle, was not sufficiently high to have caused skeletal storage in excess of the amount normally found present in fluoride-free areas.

ACID AEROSOL EFFECTS

In the oral examination of the 262 adult males, with a median age of 37 years, there was found no evidence of haemorrhagic gingivitis or erosion of the labial surfaces of the upper and lower anterior teeth which is generally indicative of exposure to excessive acid aerosol. This statement does not imply that no abnormalities were observed in the mouths of the adults examined. Since these latter findings are of no concern in this report, it will suffice to say that the oral findings of this group were quite similar to those observed in other industrial groups studied.

The examination of the 427 school children disclosed no evidence of dental erosion or gingival damage which might have been caused by acid aerosol in the community.

CONCLUSIONS

1. Fluoride intake during the period of tooth development of the 427 children was insufficient to cause mottled enamel. Fluoride exposure from sources other than water was insufficient to alter the normal inverse variation of caries attack rate and fluoride content of the communal water.

2. The fluoride content of the urine from persons examined from Donora was within normal limits, in accordance with the fluoride content of the communal water supply, which is evidence that a fluoride exposure from sources other than water was not sufficiently high to alter this direct variation.

3. Quantitative analyses of human and animal bones for fluoride showed that amounts stored in the skeletal structures were within normal limits which fails to demonstrate an abnormal exposure by inhalation or ingestion.

4. Acid aerosols were not in sufficient concentration to cause detectable ill effects to the oral structures of the 262 male adults and 427 school children examined.

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Morbidity and Mortality

H. P. Brinton

MORBIDITY: A STUDY OF SICKNESS ABSENTEEISM

Some measure of the frequency and type of disability occurring among residents of the Donora area is desirable to assist in evaluating the health status of the community. Ideally, all elements in the population should be included, males and females, children and adults, persons working and persons not employed. Little information is available, however, concerning most groups. School records do not separate sick absences from absences for other reasons. Records in the nearby hospitals are not in a form to yield information about treatment of Donora area residents. Hospital insurance plans cannot be utilized to advantage because of inadequate coverage. Although there are a number of small mutual benefit associations operating in the town, they do not maintain records useful for our purpose.

The one source of data which appeared to offer some information of value was the steel and zinc company in Donora. The zinc plant, the wire plant and the steel plant each had an employee-sponsored plan for cash payments to workers who were absent because of sickness or nonindustrial injuries. Approximately two-thirds of all the employees belonged to these plans.

It will be observed that this disability absenteeism experience applies solely to males who are members of a sick

benefit association and who work in one of the plants of the steel and zinc company. All are in the Donora environment during the working day; slightly more than two-thirds reside in the Donora area, and hence are subject to the Donora environment for the entire 24 hours each day. This is based upon the fair assumption that residence of all sick benefit association members follows the same pattern as that of all 4,916 employees who were distributed as follows as of March 1949: Donora 62.4 percent, Webster 6.4 percent, Monongahela City 17.1 percent, Charleroi 2.6 percent, Monessen 1.8 percent, and all other areas 9.7 percent.

It is well known that the rules and regulations of a sick benefit association impose certain limitations upon the sickness rates derived from data carried by the records of the association. These limitations require that appropriate allowances be made in the analysis of the data to increase the comparability of rates for different companies. The rules and regulations of the five associations contributing to the present study were accordingly analyzed, and the indicated adjustments were made. Further details in this connection are presented in a publication from the Industrial Hygiene Foundation (*1*).

Collection of Data

Sickness data for the zinc plant and the wire plant mutual benefit associations were in the possession of their respective secretary-treasurers. These were entirely employee associations and had no connection with plant management. Since sick absence cases were given serial numbers in chronological order from the time of founding of the association, there was little chance that any would be inadvertently omitted. Each case record represented money paid out because of an illness lasting 14 days or longer. To receive this money it was necessary to have a physician's certificate stating that the employee was unable to work and giving the cause of his illness. Under this procedure and considering the serious nature of the disability the chance for malingering was reduced to a minimum.

The following information was transcribed for each absence: name, check number, case number, department, age, race, date absence began, date returned to work, and cause. To compute sickness rates, the entire sick benefit association membership was divided according to age, sex, race, and department. It was found that complete data were lacking prior to 1946, so the tabulation of records was begun with the first of January of that year, thus giving data for 3 years, 1946, 1947, and 1948.

The Steel Plant Welfare Club, on the other hand, had merely the name and check number of those members receiving benefits. No details of the nature of the sickness or its duration were recorded in Donora. The original documents giving complete details were in possession of the Benefit Association of Railway Employees in Pittsburgh. To facilitate the collection of data from insurance records in Pittsburgh the Steel Plant Welfare Club prepared a list which showed by month from January 1946 through December 1948 the names of members who had been paid accident and health claims. These names were consolidated into a master alphabetical list covering the entire period. The files of the Benefit Association of Railway Employees were searched for these names and data covering all absences during the study period were transcribed. For each absence the following information was secured: Name, sex, race, age, date absence began, number of days paid, and cause. Total membership figures only were available in the steel plant so that the age distribution was calculated from a 25 percent sample of active files in the Pittsburgh office. The percentages so obtained were applied to the total membership to secure the desired population groups from which age-specific morbidity rates could be calculated.

Analysis of Results

Table 28 shows the number of absences per 1,000 males on account of sickness and nonindustrial injuries lasting 14 consecutive calendar days or longer for employees of the steel and zinc company in Donora and for two other western Pennsylvania steel companies, the data for which were collected in a similar manner. When the total sickness experience for the 3-year period (1946–48) is compared, it is observed that the steel plant has the lowest rate (60.8) followed by Com-

TABLE 28.—*Annual number of absences per 1,000 males on account of sickness and nonindustrial injuries lasting 14 consecutive calendar days or longer, by broad cause group and year in which absence began; experience of male employees of the steel and zinc company in Donora, Pa., in comparison with Company A and Company B, two other steel companies in Pennsylvania, year 1946–48, inclusive*

Cause	Annual number of absences per 1,000 males				
	Donora steel and zinc company			Company A	Company B
	Zinc	Wire	Steel		
	1946–48				
Sickness and nonindustrial injuries	79. 7	79. 3	67. 3	77. 1	(2)
Nonindustrial injuries	11. 0	10. 3	6. 5	10. 6	(2)
Sickness	68. 7	69. 0	60. 8	66. 5	79. 4
Respiratory diseases	14. 4	19. 6	17. 5	19. 5	26. 9
Digestive diseases	12. 7	19. 0	15. 6	16. 3	15. 7
Nonrespiratory-nondigestive diseases [1]	41. 6	30. 4	27. 7	30. 7	36. 8
Average number of employee-years	1, 731	3, 480	4, 800	17,546	11, 044
	1946				
Sickness and nonindustrial injuries	72. 8	78. 4	53. 1	74. 9	(2)
Nonindustrial injuries	8. 7	7. 7	5. 0	10. 0	(2)
Sickness	64. 1	70. 7	48. 1	64. 9	86. 0
Respiratory diseases	6. 9	18. 1	15. 6	16. 7	28. 8
Digestive diseases	8. 7	18. 1	9. 4	15. 6	16. 5
Nonrespiratory-nondigestive diseases [1]	48. 5	34. 5	23. 1	32. 6	40. 7
Average number of employee-years	577	1, 160	1, 600	5, 912	3, 510

[1] Ill-defined and unknown causes are included.
[2] Data not available.

TABLE 28.—*Annual number of absences per 1,000 males on account of sickness and nonindustrial injuries lasting 14 consecutive calendar days or longer, by broad cause group and year in which absence began; experience of male employees of the steel and zinc company in Donora, Pa., in comparison with Company A and Company B, two other steel companies in Pennsylvania, year 1946–48, inclusive*—Continued.

Cause	Annual number of absences per 1,000 males				
	Donora steel and zinc company			Company A	Company B
	Zinc	Wire	Steel		
	1947				
Sickness and nonindustrial injuries	83. 2	84. 5	78. 7	84. 4	(2)
Nonindustrial injuries	15. 6	12. 9	8. 1	12. 9	(2)
Sickness	67. 6	71. 6	70. 6	71. 5	83. 8
Respiratory diseases	15. 6	20. 7	19. 4	23. 6	28. 1
Digestive diseases	13. 9	19. 0	19. 4	17. 7	17. 2
Nonrespiratory-nondigestive diseases [1]	38. 1	31. 9	31. 8	30. 2	38. 5
Average number of employee-years	577	1, 160	1, 600	5, 892	3, 664
	1948				
Sickness and nonindustrial injuries	83. 2	75. 0	70. 0	71. 9	(2)
Nonindustrial injuries	8. 7	10. 4	6. 3	8. 9	(2)
Sickness	74. 5	64. 6	63. 7	63. 0	69. 3
Respiratory diseases	20. 8	19. 8	17. 5	18. 3	24. 1
Digestive diseases	15. 6	19. 8	18. 1	15. 6	13. 7
Nonrespiratory-nondigestive diseases [1]	38. 1	25. 0	28. 1	29. 1	31. 5
Average number of employee-years	577	1, 160	1, 600	5, 742	3, 870

[1] Ill-defined and unknown causes are included.
[2] Data not available.

pany A (66.5), the zinc plant (68.7), the wire plant (69.0) and Company B (79.4). With respect to respiratory diseases, the lowest rate (14.4) is found in the zinc plant. The steel plant has a rate of 17.5, Company A 19.5, the wire plant 19.6, and Company B 26.9. In 1946 and 1947 the zinc plant had the lowest respiratory disease rate and the steel plant had the next lowest rate. In 1948 the steel plant had the lowest rate.

The rate for digestive diseases was, in general, more favorable in the zinc and steel plants than in the plants of the other three associations. The zinc plant, however, had an unfavorable rate for nonrespiratory-nondigestive diseases. There is no indication that any of the three Donora plants had rates for respiratory diseases, digestive diseases or nonrespiratory-nondigestive diseases which were significantly higher than the corresponding rates found in the other Pennsylvania steel companies, namely, A and B.

Table 29 gives a comparison of the frequency rates for the steel and zinc company in Donora and Company A, according to detailed cause group. The steel and zinc company had more favorable rates for influenza and grippe, and diseases

TABLE 29.—*Annual number of absences per 1,000 males on account of sickness and nonindustrial injuries lasting 14 consecutive calendar days or longer, by cause; experience of male employees of the steel and zinc company in Donora, Pa., in comparison with Company A, another steel company in Pennsylvania, years 1946–48, inclusive*

Cause	Annual number of absences per 1,000 males	
	Donora steel and zinc company	Company A
Sickness and nonindustrial injuries	73. 6	77. 1
Nonindustrial injuries	8. 6	10. 6
Sickness	65. 0	66. 5
Respiratory diseases	17. 7	19. 5
Tuberculosis of respiratory system	. 4	0
Influenza, grippe	5. 7	7. 2
Bronchitis, acute and chronic	3. 1	1. 0
Pneumonia, all forms	4. 0	3. 0
Diseases of pharynx and tonsils	1. 4	1. 9
Other respiratory diseases	3. 1	6. 4
Digestive diseases	16. 3	16. 3
Diseases of stomach except cancer	4. 4	5. 7
Diarrhea and enteritis	1. 0	. 9
Appendicitis	6. 3	3. 8
Hernia	2. 2	3. 2
Other digestive diseases	2. 4	2. 7
Nonrespiratory-nondigestive diseases	28. 3	27. 3
Infectious and parasitic diseases	1. 2	2. 9
Rheumatism, acute and chronic	3. 6	2. 7
Neurasthenia and the like	. 5	2. 1
Neuralgia, neuritis, sciatica	. 9	. 7
Other diseases of nervous system	1. 1	. 5
Diseases of heart	4. 3	1. 8
Diseases of arteries and high blood pressure	1. 6	. 8
Other diseases of circulatory system	3. 5	3. 0
Nephritis, acute and chronic	. 5	. 1
Other diseases of genitourinary system	3. 3	3. 7
Diseases of skin	1. 0	2. 0
Diseases of organs of movement except diseases of joints	. 7	3. 5
All other diseases	6. 1	3. 5
Ill-defined and unknown causes	2. 7	3. 4
Average number of employee-years	10, 011	17, 546

of the pharynx and tonsils, but it had higher rates for tuberculosis of the respiratory system, acute and chronic bronchitis, and pneumonia, all forms. However, all these differences in respiratory diseases are slight.

The rate for the group of digestive diseases was the same for both companies. When the group is subdivided it appears that the steel and zinc company had lower rates for diseases of the stomach except cancer, and hernia. Among the nonrespiratory-nondigestive diseases with higher rates for Donora workers were acute and chronic rheumatism; neuralgia, neuritis and sciatica; other diseases of the arteries and high blod pressure; other diseases of the circulatory system; and acute and chronic nephritis.

For the 3-year period, duration of sickness and nonindustrial injuries showed little difference between employees in Donora and those in Company A. Table 30 shows that there were 73.6 absences per 1,000 males that lasted 14 days or more

TABLE 30.—*Annual number of absences per 1,000 males on account of sickness and nonindustrial injuries disabling for the indicated number of consecutive calendar days or more, by year in which absence began; experience of male employees of the steel and zinc company in Donora, Pa., in comparison with Company A, another steel company in Pennsylvania, years 1946–48, inclusive*

Duration of absence in calendar days	Donora steel and zinc company				Company A			
	1946–48	1946	1947	1948	1946–48	1946	1947	1948
	Annual number of absences per 1,000 males							
14 days or more	73.6	65.3	81.5	74.0	77.1	74.9	84.4	71.9
21 days or more	54.0	47.9	58.7	55.4	56.8	56.0	63.1	51.0
28 days or more	44.9	40.5	48.2	45.8	44.1	42.8	49.1	40.4
35 days or more	38.9	33.6	44.4	38.7	34.5	33.8	35.8	33.8
42 days or more	32.9	29.1	39.3	30.3	28.0	28.8	29.5	25.6
49 days or more	26.1	23.4	32.4	22.5	21.8	21.7	23.6	20.2
	Number of absences							
14 days or more	737	218	272	247	1,353	443	497	413
21 days or more	541	160	196	185	996	331	372	293
28 days or more	449	135	161	153	774	253	289	232
35 days or more	389	112	148	129	605	200	211	194
42 days or more	329	97	131	101	491	170	174	147
49 days or more	261	78	108	75	383	128	139	116
Average number of employee-years	10,011	3,337	3,337	3,337	17,546	5,912	5,892	5,742

among steel and zinc company employees, compared with a rate of 77.1 for Company A. For durations of 49 days or more the corresponding rates were 26.1 and 21.8.

Age-specific rates for certain broad sickness groups are presented in table 31. In comparison with Companies A and B the rate for respiratory diseases among the local steel and zinc company workers under 35 years of age are considerably lower. For ages 35-44 the rates were about the same and for ages 45 years and over Company B had a much higher respiratory rate. A common pattern was noted with respect to digestive diseases and nonrespiratory-nondigestive diseases. Among persons under 35 years of age the Donora plant had lower rates, but in the two older age groups the position was reversed, and Companies A and B were, in general, in a more favorable position. Again, the differences were not very great in any of the sickness groups.

A distribution of absences on account of sickness and nonindustrial injuries by year and month in which absence began shows the effect of the smog of October 1948 in that there was an unexpected rise in absences in the steel and zinc company in Donora, and no such rise in Companies A and B.

MORTALITY

Mortality data furnish a universally available source for the measurement of certain aspects of the health of a community. The advantages of using death certificates as a source of data lie in the relative accuracy of the facts recorded and in the completeness of coverage. Once mortality rates have been computed for any area, there are standards for comparison easily obtainable for any specific age, sex, or race group. In a community such as Donora with relatively little migration, mortality rates afford some clues as to the cumulative effect of environmental influences. If there were a large excess of certain serious acute or chronic diseases, there should be some reflection of this fact in the mortality rates.

Source of Data

Photostatic copies of all death certificates for residents of the Borough of Donora covering the period 1945–48 were secured from the Bureau of Vital Statistics, Pennsylvania Department of Health. All deaths of Donora residents occurring any place within the State of Pennsylvania were included, but residents who died in other states had been omitted. As a check on the completeness of the records in the State office, a list of all burials from 1945 through 1948 was obtained from local undertakers. When differences were disclosed by the matching of names from these two lists, measures were taken to eliminate the inconsistencies. Stillbirths were not counted, but all deaths of infants were included even if they lived only a few minutes after birth.

In addition to an accurate record of deaths, it was necessary to develop a reliable population base on which to compute mortality rates. Pittsburgh, Pa., was chosen as a control for the study of mortality trends. Population estimates for this city and for Donora were prepared after consultation with officials of the U. S. Bureau of the Census. The date of January 1, 1947, was selected for the population base since it was the midpoint of the period being studied.

A method for estimating the population of Pittsburgh which appeared applicable under the present circumstances was as follows: The percent distribution by sex and age of the total population was obtained for the city of Pittsburgh in 1940, for the Pittsburgh Metropolitan district in 1940, and for the Pittsburgh Metropolitan district in 1947 (estimated). For each specific sex and age group the percent of the city population in 1940 was divided by the percent of the Metropolitan district population in 1940 and the result was multiplied by the percent of the Metropolitan district population in 1947, giving the estimated percent of the population of the city for April 1947. For each sex and age-specific group the estimated percent in the city of Pittsburgh, November 1946, was multiplied by 3 and the esti-

TABLE 31.—*Annual number of absences per 1,000 males on account of sickness and nonindustrial injuries lasting 14 consecutive calendar days or longer, by age and broad cause group; experience of male employees of the steel and zinc company in Donora, Pa., in comparison with Company A and Company B, two other steel companies in Pennsylvania, years 1946–48, inclusive*

Age in years	Annual number of absences per 1,000 males			Number of absences		
	Donora steel and zinc company	Company A	Company B	Donora steel and zinc company	Company A	Company B
	Sickness and nonindustrial injuries					
All ages	[2] 73.6	[2] 77.1	(3)	[2] 737	[2] 1,353	(3)
Under 35	45.9	75.5	(3)	177	485	(3)
35–44	73.5	61.3	(3)	171	269	(3)
45 and over	100.7	88.6	(3)	386	597	(3)
	Sickness					
All ages	[2] 65.0	[2] 66.5	79.4	[2] 651	[2] 1,167	877
Under 35	40.0	61.0	78.5	154	392	399
35–44	61.9	55.2	64.1	144	242	194
45 and over	91.3	78.8	96.7	350	531	284
	Respiratory diseases					
All ages	17.7	[2] 19.5	26.9	177	[2] 343	297
Under 35	8.0	16.3	23.0	31	105	117
35–44	18.1	16.4	20.5	42	72	62
45 and over	27.1	24.3	40.2	104	164	118
	Digestive diseases					
All ages	[2] 16.3	16.3	15.7	[2] 163	286	174
Under 35	14.3	19.6	18.5	55	126	94
35–44	16.3	14.2	12.6	38	62	38
45 and over	18.0	14.6	14.3	69	98	42
	Nonrespiratory-nondigestive diseases [1]					
All ages	[2] 31.0	30.7	36.8	[2] 311	538	406
Under 35	17.7	25.1	37.0	68	161	188
35–44	27.5	24.6	31.0	64	108	94
45 and over	46.2	39.9	42.2	177	269	124
	Average number of employee-years					
All ages	10,011	17,546	11,044	10,011	17,546	11,044
Under 35	3,852	6,422	5,080	3,852	6,422	5,080
35–44	2,325	4,386	3,026	2,325	4,386	3,026
45 and over	3,834	6,738	2,938	3,834	6,738	2,938

[1] Ill-defined and unknown causes are included.
[2] A few absences of persons of unknown ages are included.
[3] Data are not available.

mated percent in the city of Pittsburgh, April 1947 was multiplied by 2. The total was divided by 5 to obtain the estimated percent in each specific age and sex group for January 1947. These percentages were applied to the total population of Pittsburgh (separately estimated) for January 1947, in order to secure an estimated figure for each age and sex group.

Population estimates for the Borough of Donora were based on the U. S. Census returns for April 1940, and a special census carried out by the Borough tax assessor in April 1947. For each age and sex specific group the percent in April 1940 was multiplied by 3 and the percent in April 1947 was multiplied by 81. This total was divided by 84 and the percentages were applied to the total population (estimated for January 1947) to obtain the population of the various age and sex groups.

Unusual Weather Periods Prior to 1948

According to available weather records, since 1920 there were two periods when severe smog conditions were likely to have existed in Donora (*2*). The first period was from October 5–13, 1923, and the second from October 7–18, 1938. The original certificates of death occurring in Donora during October and November for 1923 and 1938 were examined. In 1923 the three deaths occurring from October 5–13 were attributed to accidents in two instances, and to bronchopneumonia for a child under 1 year of age. During the remainder of that month there were four deaths caused as follows: Accident, cancer of breast, erysipelas, and acute dilatation of heart. In November 1923, there were only two deaths, one due to an accident and the other to cirrhosis of the liver.

The October 7–18 period in 1938 showed a death on the tenth due to bronchial asthma for a 69-year-old white male, a death on the fifteenth for a 65-year-old white female which was due to diabetes and cardiac failure, and a death on the same day of a 2-year-old child due to an accident. Later in October there was a death from each of the following causes: Accident, cardiovascular-renal disease, cardiac dilatation, appendicitis, and lobar pneumonia.

It does not appear that deaths at or shortly after either of these periods were occurring above the usual rate. The relation of the reported causes of death to possible smog cannot be determined from data available to us at this time.

For the month of April 1945 there were 19 deaths which is the greatest number during any month of the 4-year period, 1945–48. The month of October 1948 which included the smog showed 17 deaths in the Borough of Donora. During April 7–14, 1945, the meteorological factors of low average daily wind velocity and high average early morning valley stability made this period the most favorable for nocturnal retention of smoke during the four years 1945–1948, if the October 27 to November 2, 1948 period is excluded (*2*).

Deaths in Donora did not reach a peak in any one period in April 1945, but were consistently above the weekly average for the entire month. Diseases of the heart accounted for nine deaths, intracranial lesions of vascular origin for five deaths, cancer for two deaths, and pulmonary tuberculosis, lobar pneumonia, and accident for one death each. The number of deaths caused by heart disease and the number caused by intracranial lesions of vascular origin were much higher than found for any other April in the 4-year period in Donora. The heart disease deaths were in most instances called myocarditis or myocardial failure. Intracranial lesions were designated as cerebral embolism or cerebral haemorrhage.

These findings suggest that the indicated atmospheric conditions of April 1945 may have contributed to the relatively higher incidence of deaths from cardiovascular disease during that period.

Deaths in Donora Borough, 1945–48

A detailed study of mortality in the Donora area is limited to the Borough of Donora because a count of residents who died away from home cannot be made for residents of areas outside the Borough. Table 32 and figure 54 show the annual death rate per 1,000 persons for Pittsburgh and for Donora on a monthly basis from January 1945 through December, 1948. At first glance it is evident that there were 2 months when deaths in Donora were greatly in excess of the average. The mortality rate for April 1945, was 18.8 and for October 1948, which includes the recent smog, was 16.3. In Pittsburgh during these two periods the mortality rates were not above the average, being 11.2 and 9.6, respectively. During December 1945 and January 1946 mortality rates were high for both cities. This may probably be attributed to a respiratory disease epidemic which occurred at that time (*3*). The months of the year 1948 showed a trend toward more favorable mortality rates for Pittsburgh and Donora until October, at which time the former city showed the usual seasonal increase while in the latter city the rate increased more than four times.

Monthly fluctuations in mortality rates were much greater in Donora than Pittsburgh, as would be expected because of the small number of cases involved. Months having a mortality rate less than five were August 1946, June and October 1947, and March, July, and September 1948. The lowest month for Pittsburgh was July 1948 when the rate fell to 7.4. For the entire period of 48 months Donora had a higher rate than Pittsburgh only in April and September 1945, and January, October, and November 1948. It is noteworthy that of these five months, in only two, namely September 1945, and January 1948, were the atmospheric conditions not conducive to the development of smog.

TABLE 32.—*Death rate per 1,000 persons (annual basis) for Pittsburgh and Donora, Pa., according to month and year of death, 1945–48, inclusive*

Month	1945		1946		1947		1948	
	Pittsburgh	Donora	Pittsburgh	Donora	Pittsburgh	Donora	Pittsburgh	Donora
January	12.2	7.7	13.0	11.5	10.7	10.5	11.2	11.5
February	12.2	6.4	11.8	11.6	12.7	7.4	11.7	9.5
March	10.9	9.6	11.2	8.6	13.1	9.6	10.7	4.8
April	11.2	18.8	11.5	5.0	13.4	8.9	9.3	5.0
May	11.2	9.6	9.8	8.6	11.2	6.7	9.1	7.7
June	10.1	7.9	10.0	6.0	9.9	3.9	8.5	7.9
July	9.7	7.7	9.8	7.7	11.0	8.6	7.4	3.8
August	10.0	7.7	9.2	2.8	10.7	9.6	9.0	5.8
September	10.0	11.8	10.5	6.0	10.2	7.0	7.8	3.9
October	9.8	9.6	12.0	7.7	12.4	3.8	9.6	16.3
November	11.3	5.0	12.0	7.0	12.0	8.9	9.8	12.8
December	15.2	14.4	12.4	6.7	12.2	11.5	11.0	7.7

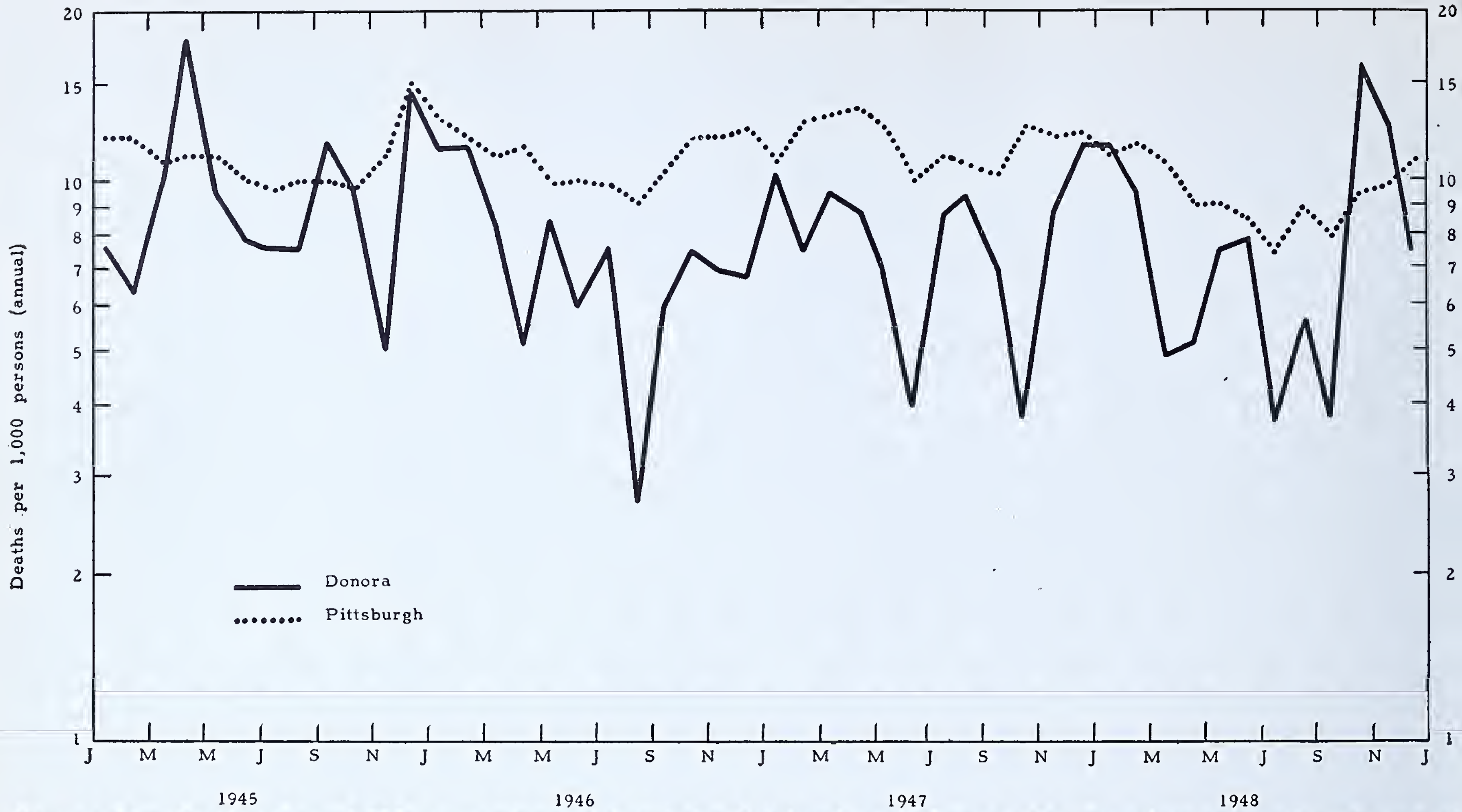

FIGURE 54.—*Death rate per 1,000 persons (annual basis) for Pittsburgh and Donora, Pa., according to month and year of death, 1945–48, inclusive. (Note.—Intervals on the horizontal axis represent 2-month periods. The graph is determined by points plotted at 1-month intervals. Logarithmic vertical scale.)*

Table 33 shows the seasonal fluctuation of deaths in Donora as compared with the fluctuation for Pittsburgh and for the entire United States. The seasonal index for a particular month shows the relative amount that the rate for the month is above or below the 12-month average. When the indexes for the October months, and the April months are corrected by removing from the calculation the deaths for April 1945 and October 1948, respectively, it is observed in table 33 that the seasonal trend for deaths in Donora follows closely the trends for Pittsburgh and for the entire United States. The uncorrected indexes were found to be 1.14 instead of 0.75 for April and 1.13 instead of 0.84 for October, and the total increases were due in each instance to the single months of April of 1945 and October of 1948. There is no indication that Donora deaths follow a different seasonal pattern than the rest of the country except for the presence of an occasional critical period which can be readily identified. The variation from winter to summer is slightly more pronounced for Donora.

TABLE 33.—*Seasonal index of deaths in Pittsburgh and Donora, Pa., compared with that of the United States as a whole, based on experience of previous years*

Month	Seasonal index of deaths		
	United States [1]	Pittsburgh [2]	Donora [2]
January	1. 12	1. 09	1. 24
February	1. 11	1. 12	1. 05
March	1. 07	1. 06	. 98
April	1. 02	1. 05	[3] . 75
May	. 98	. 95	. 98
June	. 95	. 89	. 78
July	. 94	. 87	. 84
August	. 90	. 90	. 78
September	. 90	. 89	. 87
October	. 96	1. 01	[4] . 84
November	. 99	1. 04	1. 02
December	1. 06	1. 17	1. 22

[1] Based on experience of 1937–46.
[2] Based on experience of 1945–48.
[3] Deaths in April 1945 are excluded.
[4] Deaths in October 1948 are excluded.

Mortality rates per 100,000 are compared for Donora and the city of Pittsburgh according to broad cause groups in table 34. It will be observed that the Donora rate was generally lower than the rate for Pittsburgh. Among persons of all ages the only causes which showed a higher rate for Donora were diabetes, ulcers of the stomach or duodenum, nephritis, and diseases of pregnancy. In all instances the excess was not significant. When these deaths were divided into three broad age groups it appeared that among the older age group (45 to 64 years) a larger number of causes showed a slight excess for Donora. At ages 45–64 years the Donora mortality experience was less favorable than Pittsburgh for infectious diseases, cancer, diabetes, intracranial lesions, ulcers of the stomach or duodenum, accidents, and the "all other" group. However, not one of the differences was statistically significant. On the other hand in this same group, heart disease was found to be significantly higher in Pittsburgh, the rate reaching 567 compared with a rate of 327 in Donora. Among persons 65 years of age and over the mortality rate for diabetes, nephritis, suicide, and the "all other" group was higher for Donora. The only significant differ-

TABLE 34.—*Average annual number of deaths in Pittsburgh and in Donora, Pa., for the 4-year period 1945–48, and rate per 100,000 persons, according to age and cause of death*

Cause	All ages		Age in years					
			Under 45		45–64		65 and over	
	Pittsburgh	Donora	Pittsburgh	Donora	Pittsburgh	Donora	Pittsburgh	Donora
	Average annual number							
All causes	7, 460	102	1, 475	18	2, 573	42	3, 412	42
Infectious diseases	61	1	22	0	27	1	12	0
Tuberculosis	297	2	152	1	116	1	29	0
Cancer	1, 044	16	113	1	467	9	464	6
Diabetes mellitus	205	5	13	0	84	3	108	2
Intracranial lesions of vascular origin	710	11	40	0	240	6	430	5
Heart disease	2, 474	27	179	2	881	9	1, 414	16
Pneumonia and influenza	410	4	112	2	123	1	175	1
Ulcer of stomach or duodenum	39	1	6	0	25	1	8	0
Cirrhosis of liver	92	0	15	0	47	0	30	0
Nephritis	387	7	39	1	125	2	223	4
Diseases of pregnancy	26	1	25	1	1	0	0	0
Diseases of the 1st year	270	4	270	4	0	0	0	0
Suicide	66	1	22	0	32	0	12	1
Homicide	31	0	23	0	6	0	2	0
Accidental deaths	389	5	146	1	109	3	134	1
All other	959	17	298	5	290	6	371	6
	Rate per 100,000 persons							
All causes	1, 086	826	306	202	1, 654	1, 526	6, 793	6, 069
Infectious diseases	9	8	5	0	17	36	24	0
Tuberculosis	43	16	32	11	75	36	58	0
Cancer	152	130	23	11	300	327	924	867
Diabetes mellitus	30	41	3	0	54	109	215	289
Intracranial lesions of vascular origin	103	89	8	0	154	218	856	722
Heart disease	360	219	37	23	567	327	2, 815	2, 312
Pneumonia and influenza	60	32	23	23	79	36	348	145
Ulcer of stomach or duodenum	6	8	1	0	16	37	16	0
Cirrhosis of liver	13	0	3	0	30	0	60	0
Nephritis	56	57	8	11	80	73	444	578
Diseases of pregnancy	4	8	5	11	1	0	0	0
Diseases of the 1st year	39	32	56	45	0	0	0	0
Suicide	10	8	5	0	21	0	24	145
Homicide	5	0	5	0	4	0	4	0
Accidental deaths	57	40	30	11	70	109	267	144
All other	139	138	62	56	186	218	738	867
Population as of Jan. 1947	688, 000	12, 346	482, 288	8, 901	155, 488	2, 753	50, 224	692

ence in any cause among the oldest group was pneumonia and influenza which had a rate of 348 for Pittsburgh and 145 for Donora.

The fact that people appeared to die less frequently of pneumonia in Donora than in Pittsburgh was investigated. Original death certificates for the 4-year period were studied by a physician to find all deaths mentioning pneumonia or influenza and to question for each death whether pneumonia or influenza was a primary or secondary cause. Two additional cases were found by this procedure which raised the pneumonia and influenza mortality rate for Donora from 32 to 40 per 100,000 which is still considerably less than the Pittsburgh rate of 60.

Death Ratios

To test the significance of the Donora mortality data further, information was made available by the National Office of Vital Statistics on ratios for certain causes of death for the towns adjacent to Donora compared with that for Donora. Table 35 shows the ratio of the number of actual deaths to the expected number of deaths from specified causes for Washington County and certain of its towns including Donora. An indirect adjustment for age, race, and sex was made by applying a set of standard death rates (Pennsylvania, 1940) specific for these characteristics, to the age-race-sex distribution of the population for each area as enumerated in 1940. The results were multiplied by five to obtain the number of deaths from a particular cause which would be expected to occur in the population if the specific mortality for Pennsylvania in 1940 were to prevail for a 5-year period.

It will be observed that Donora had the most favorable ratio of any of the four towns in Washington County. Considering the most unfavorable ratio according to cause in these towns, Donora appeared first for cancer, Canonsburg

TABLE 35.—*Ratio of registered to expected deaths for specified causes: Washington County, Pa., and urban places having populations of 10,000 or more in 1940; 5-year total, 1938–42* [1]

Cause of death	Washington County	Donora	Canonsburg	Charleroi	Washington	Balance of County
All causes	0. 91	0. 90	1. 01	0. 95	1. 10	0. 87
Tuberculosis (all forms)	. 75	. 67	. 64	. 80	. 85	. 75
Cancer and other malignant tumors	. 88	1. 25	. 96	. 94	1. 05	. 80
Diabetes mellitus	. 79	1. 07	1. 05	1. 07	. 84	. 72
Intracranial lesions of vascular origin	1. 14	1. 03	1. 00	. 95	1. 49	1. 10
Diseases of the heart	. 77	. 66	. 75	. 81	. 93	. 75
Pneumonia (all forms) and influenza	. 92	1. 00	1. 03	. 63	1. 33	. 85
Nephritis	. 84	. 89	1. 04	1. 93	. 95	. 72
Accidental deaths	1. 16	. 98	1. 53	. 74	1. 20	1. 16

[1] Based on calculations provided by the National Office of Vital Statistics.

NOTE.—"In computing the expected numbers of deaths for a specified cause, the age-race-sex specific death rates for that cause for Pennsylvania in 1940 were used as the standard. The specific rates were applied to the corresponding distribution of the 1940 enumerated population of each area and the results multiplied by five to obtain the expected number for a 5-year period."—*National Office of Vital Statistics.*

for accidents, Charleroi for nephritis, and Washington for tuberculosis, intracranial lesions, diseases of the heart, and pneumonia and influenza. Donora had the most favorable ratio for diseases of the heart and for nephritis. It had a slightly greater number of deaths than expected for diabetes and for intracranial lesions of vascular origin. Pneumonia and influenza mortality was exactly what would be expected from the Pennsylvania experience.

These data confirm the impression gained previously that diseases of the heart and of the respiratory system, as causes of death, are not higher in Donora than in the adjacent towns.

Deaths During the 1948 Smog Period

Since it is known that the weather conditions which existed in Donora in October 1948 were widespread throughout the Monongahela Valley, it is of interest to examine the number of deaths which occurred during that period in several surrounding towns. Table 36 shows the number of deaths for October 24 to November 6, compared with the number occurring in three 2-week periods before, and three periods after, that time. It should be remembered that for areas other than Donora the deaths are by place of occurrence rather than by place of residence. To get a more nearly complete picture, however, the nearby areas in which persons were most likely to go for hospital treatment were searched and deaths occurring there were allocated to place of residence.

It will be noted that the areas nearest Donora on the south and east or up river side, had the greatest increase during the smog period. Thus Rostraver Township which includes the towns of Webster and North Belle Vernon, had 11 deaths during the smog period compared with three or four deaths in the earlier 2-week periods. Monessen had 9 deaths compared with 4 or 5 previously. Even in November and December, when deaths would show a normal seasonal increase, the maximums reached during the smog period were not attained in these two areas. Further up river the towns of North Charleroi and Charleroi did not show any excess of deaths during the smog period. Their peak was reached September 12–25 when there were seven deaths compared with four during the smog.

Monongahela City, which adjoins Donora on the northwest, or down river side, had only one death during the smog and no deaths in the following 2-week period. Normally, it had two or three deaths during 2 weeks. The next town down river is Elizabeth, where five deaths occurred during the smog period, which is slightly in excess of the normal one or two deaths. Clairton is situated just beyond Elizabeth and is directly north of Donora. Although this town usually had four deaths in a 2-week period there were no deaths from October 24 to November 6, 1948.

Further understanding of the mortality experience in these towns during the smog period may be gained by an examination of the age and cause of death for persons who died

TABLE 36.—*Number of deaths which occurred in Donora, Pa., and certain other Monongahela Valley towns by 2-week periods from Sept. 12 to Dec. 18, 1948*

Period	Total	Donora	Rostraver Township [1]	Monessen	Charleroi [2]	Monongahela	Elizabeth [3]	Clairton
Total	187	35	36	36	30	13	12	25
Sept. 12–Sept. 25	25	2	4	5	7	2	1	4
Sept. 26–Oct. 9	21	3	4	5	2	2	1	4
Oct. 10–Oct. 23	22	1	3	4	6	3	1	4
Oct. 24–Nov. 6	46	16	11	9	4	1	5	0
Nov. 7–Nov. 20	25	7	6	4	2	0	2	4
Nov. 21–Dec. 4	27	4	6	6	4	2	2	3
Dec. 5–Dec. 18	21	2	2	3	5	3	0	6

[1] Includes Webster and Borough of North Belle Vernon.
[2] Includes North Charleroi and Charleroi.
[3] Includes West Elizabeth and Elizabeth.

NOTE.—Based on death certificates filed by place of occurrence in the Pennsylvania State Department of Health, except that deaths occurring in Pittsburgh, McKeesport, New Eagle and North Charleroi have been allocated to place of residence.

from October 24 to November 6. Table 37 shows that Rostraver Township and Monessen had a number of deaths at the peak of the smog period which resembled with respect to age and cause those occurring in Donora at the same time. Certain of these deaths were for Rostraver Township residents living in Webster and have been described in detail elsewhere in this report. Other deaths were in the rural area between Webster and Monessen. There were no deaths in Charleroi on October 29, 30, or 31, when deaths in Donora were highest. No Charleroi deaths mentioned asthma. Monongahela City had only one death, which was on October 26. Of the five deaths in Elizabeth, three occurred before October 28 and one, due to nephritis, was on November 3. One death, said to be due to bronchial asthma, occurred on October 30.

The relatively small populations from which these Monongahela Valley deaths are derived make it difficult to draw conclusions as to the mortality in particular areas. In general, it would appear that those areas lying near Donora on the south and east had a larger increase in the number of deaths for the period from October 24 to November 6 than did areas further south or to the north or west.

DISCUSSION

Morbidity and mortality experiences in Donora reflect certain aspects of general health conditions in the community. Both of these indexes emphasize the importance of the 1948 smog period as may be readily observed from figure 55 which plots the number of deaths and sick absences according to 2-week periods from 1946 through 1948. The peak for deaths in October 1948 is much more noticeable than for absences of 14 days or longer. A possible explanation for this difference is the fact that a number of deaths occurred among the

TABLE 37.—*Sex, race, age, and cause of death, for persons dying in certain Monongahela Valley towns between Oct. 24 and Nov. 6, 1948*

Date of death (1948)	Sex	Race	Age in years	Cause
	Rostraver Township [1]			
Oct. 24	Male	White	53	Coronary occlusion.
Oct. 25	Female	do	67	Coronary occlusion.
Oct. 29	Male	do	76	Asthma, hypertension.
Oct. 30	Female	Negro	58	Cardiac asthma, myocarditis.
Oct. 30	do	do	55	Status asthmaticus.
Oct. 30	Male	White	67	Chronic myocarditis.
Oct. 31	do	do	78	Coronary occlusion.
Nov. 1	do	do	69	Suicide.
Nov. 5	do	do	74	Coronary occlusion.
Nov. 6	Female	do	21	Toxemia of pregnancy.
Nov. 6	Male	do	81	Cerebral haemorrhage.
	Monessen			
Oct. 28	Male	White	63	Cardiac dilatation, myocarditis.
Oct. 28	Female	Negro	70	Cardiorenal-vascular disease.
Oct. 28	Male	White	63	Cardiac asthma.
Oct. 29	do	do	70	Apoplexy, myocarditis.
Oct. 29	do	do	66	Chronic myocarditis.
Oct. 30	do	do	75	Cardiac asthma, myocarditis.
Nov. 1	do	do	76	Chronic coronary artery disease.
Nov. 2	do	do	76	Asthmatic bronchitis.
Nov. 3	Female	do	65	Cancer of rectum.
	Charleroi [2]			
Oct. 27	Female	White	80	Acute myocardial infarction.
Oct. 28	do	do	85	Coronary occlusion.
Nov. 3	Male	do	79	Coronary occlusion.
Nov. 5	do	do	63	Coronary artery disease.
	Monongahela City			
Oct. 26	Male	Negro	66	Chronic myocarditis.
	Elizabeth [3]			
Oct. 25	Male	White	84	Coronary occlusion.
Oct. 25	Female	do	92	Hypostatic pneumonia.
Oct. 27	do	do	54	Cancer of uterus.
Oct. 30	Male	do	72	Bronchial asthma.
Nov. 3	Female	do	79	Apoplexy, nephritis.

[1] Includes Webster and Borough of North Belle Vernon.
[2] Includes North Charleroi and Charleroi.
[3] Includes West Elizabeth and Elizabeth.

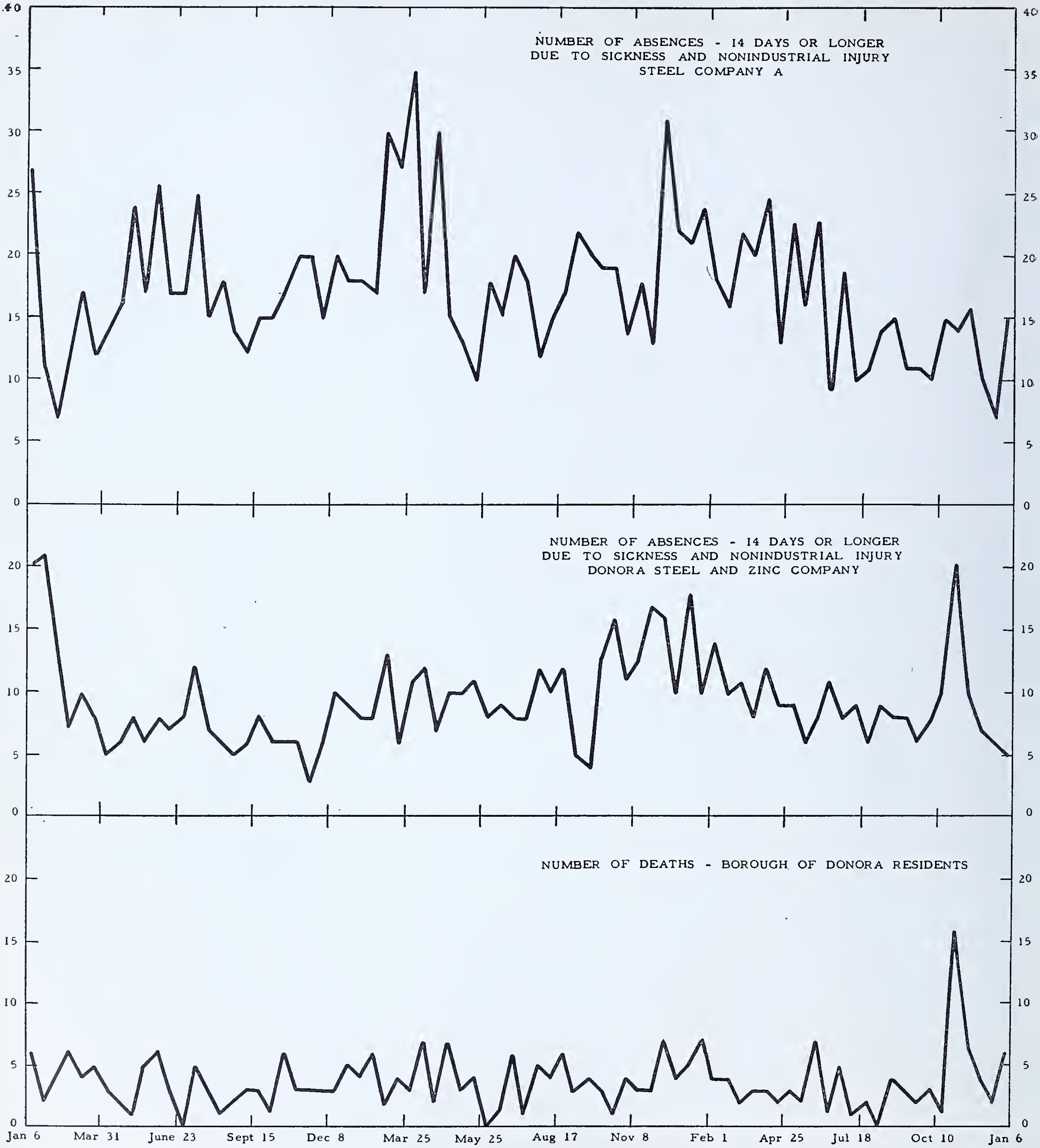

FIGURE 55.—*Number of absences on account of sickness and nonindustrial injuries lasting 14 calendar days or longer among male employees of steel Company A, and the Donora steel and zinc company, by 2-week periods in which absences began, and number of deaths of Donora Borough residents during the same periods, January 6, 1946, to December 19, 1948. (Note.—Intervals on the horizontal axis represent 12-week periods. The graph is determined by points plotted at 2-week intervals.)*

older nonworking population. Although a large proportion of the steel and zinc company workers may have been sick at the time of the smog, there were relatively few who were disabled for 14 days or longer. However, the sharp rise in the number of cases of sickness and nonindustrial injury in October 1948, observed among the steel and zinc company employees was not shown by steel company A, which was also located in western Pennsylvania. The rise during the winter of 1947–48 was observed for both companies.

SUMMARY AND CONCLUSIONS

Age-specific morbidity and mortality rates failed to show causes of illness and death which were significantly higher for Donora than other areas nearby. Sickness experience for a 3-year period revealed that the number of absences per one thousand males on account of different kinds of sickness was 65.0 for the Donora steel and zinc company compared with 66.5 and 79.4 for the two other western Pennsylvania steel companies used as controls. For respiratory diseases only, the rate for Donora was 17.7 compared with 19.5 and 26.9 for the other companies. The average annual number of deaths per 1,000 persons (1945–48) was 8.3 for Donora and 10.9 for Pittsburgh. Most of the differences in the mortality rates for specific causes could have been due to chance alone. Significantly higher death rates in Pittsburgh were observed for heart disease among persons 45–64 years of age, and for pneumonia and influenza among persons 65 years of age and over. The mortality rate for tuberculosis was low in Donora. Deaths due to disease of the heart and respiratory system were not increased in Donora. Death ratios for certain towns adjacent to Donora tended to confirm this impression.

Seasonal mortality and morbidity rates in Donora follow the usual pattern with an increase during the winter. Increases in mortality rates during April 1945 and October 1948 were apparently due to special circumstances affecting Donora only. When the excess deaths in these critical periods were removed, there was no evidence of deviation from normal seasonal trends. Apparently only in periods of crisis was the Donora health different from other nearby towns.

Deaths were examined for certain periods during 1923 and 1938 when possible smog conditions existed in Donora. It does not appear that deaths at or shortly after either of these two periods were occurring above the usual rate. In April 1945 the death rate for Donora was higher than for any month during 1945–48. Findings in regard to atmospheric conditions suggest that the environment may have contributed to the higher incidence of deaths due to cardiovascular disease.

Although the numbers are too small to draw valid conclusions, it is of interest to note that at the time of the smog, areas south and east of, and nearby, Donora Borough showed a greater rise in deaths than did areas to the north and west.

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(*2*) Willett, H. C.: Personal communication. May 4, 1949.

(*3*) Gafafer, W. M.: Sickness absenteeism among male and female industrial workers during 1945, with a note on the respiratory epidemic of 1945–46. *Pub. Health Rep.* 61: 1620 (Nov. 8, 1946). (Reprint No. 2755.)

III. Atmospheric Studies

INTRODUCTION

Based on all available evidence, it was early apparent that no unusual substance had been emitted into the atmosphere and that there was no accidental occurrence which produced unusual quantities of some particular substance during the smog period of October 1948 in the Donora area. Hence, it was believed that the same kinds of contaminants which were present during the October 1948 episode would also be present during the period of the study.

Because of these assumptions, it was believed that information on sources, amounts produced and concentrations of contaminants in the general atmosphere, in conjunction with the micrometeorology of the valley, would give a picture of the over-all atmospheric pollution of the area. The correlation of these data with weather data which were available under the conditions at the time of the episode should be helpful in attempting to reconstruct the conditions which existed during the smog and thus aid, in conjunction with the biological findings, in analyzing the possible cause of the episode.

To obtain information on contaminants likely to be present, their sources, amounts and dissemination in the general atmosphere, consideration was given to industrial plants, trains, boats, automobiles and domestic sources. The distribution of the contaminants into the general atmosphere was determined by routine sampling at 12 selected stations throughout the area. Concurrently with the determination of the contaminants in the general atmosphere micrometeorological data were collected at 8 stations.

INVESTIGATION OF ATMOSPHERIC CONTAMINANTS

Collection and Determination

Harold J. Paulus, Andrew D. Hosey, Robert B. Crothers, and Dohrman H. Byers

COLLECTION OF CONTAMINANTS[1]

Plants

In an effort to measure the degree of atmospheric pollution from industrial plants, the procedure used in this study was, in some respects, quite different from the usual methods employed by the industrial hygienist. Many of the conventional methods of air sampling would not suffice under the wide variations of conditions encountered. In most instances, each stack sampled was handled as a separate problem and equipment or apparatus was adapted for the particular stack under study. Much of the work done in the beginning of the study was by trial and error since there were always present several contaminants, different temperature conditions, and varying amounts of moisture or acid mists.

The two plants were divided for sampling purposes as follows:

Zinc plant.—(1) Roasters, (2) sintering plant, (3) zinc spelters, (4) waste heat boilers, (5) Waelz plant, (6) dross plant, (7) sulfuric acid plant, and (8) cadmium plant.

Steel plant.—(1) Blast furnaces, boilers and sintering plant, (2) open hearth furnaces, (3) soaking pits, desurfacer and boilers, and (4) wire mill.

The atmospheric contaminants to be studied were deduced from the raw materials used and the processes to which the pertinent materials were subjected. Raw materials and intermediate products were analyzed by the spectrographic method for the following toxic elements:

Antimony.	Phosphorus.
Arsenic.	Selenium.
Cadmium.	Sulfur.
Germanium.	Tellurium.
Indium.	Thallium.
Lead.	Zinc.

From this information, it was decided to sample for the following constituents:

Total particulate matter.	Arsenic.
Lead.	Sulfur dioxide.
Cadmium.	Total sulfur.
Zinc.	Carbon dioxide.
Iron.	Carbon monoxide.
Chloride.	Oxygen.
Fluoride.	

[1] By Harold J. Paulus, Andrew D. Hosey, and Robert B. Crothers.

In addition to the above, samples for the following contaminants were collected in those stacks where their presence was indicated:

Oxides of nitrogen.	Stibine.
Acid gases.	Manganese.
Hydrogen.	Iron carbonyl.
Arsine.	

Qualitative tests for hydrogen sulfide and cyanide were made in stacks at the cadmium plant.

Collection methods and apparatus.—Samples for the determination of total particulate matter (weight), lead, zinc, cadmium, iron and manganese were collected generally with an electrostatic precipitator (*1*). A sampling rate of 2 cubic feet per minute was used because of the large amount of particulate matter encountered in most stacks. At the usual rate of flow for this instrument (3 cfm), it was found that some material passed through the instrument instead of adhering to the collecting tube. Another problem was the fact that the corona could not be observed when the sampling tube was in the stack. One of the new Mine Safety Appliances power packs was tried and a more uniform high voltage was obtained, and it was possible by a glance at the voltmeter on the instrument panel to determine whether or not arcing occurred and whether or not sufficient voltage was supplied to the electrode.

Since the temperature ranged from 135° F. to 1,000° F. in the majority of the stacks sampled, it was necessary to use a water-cooled sampling tube. The type of tube used is shown in figure 56. When an impinger tube was used, connection was made at the threaded end of the tube D.

When an electrostatic precipitator was used, piece B was screwed onto end D. About two turns of rubber tape (splicing compound) was wound over the end of B and the precipitator tube C was slipped over this tape.

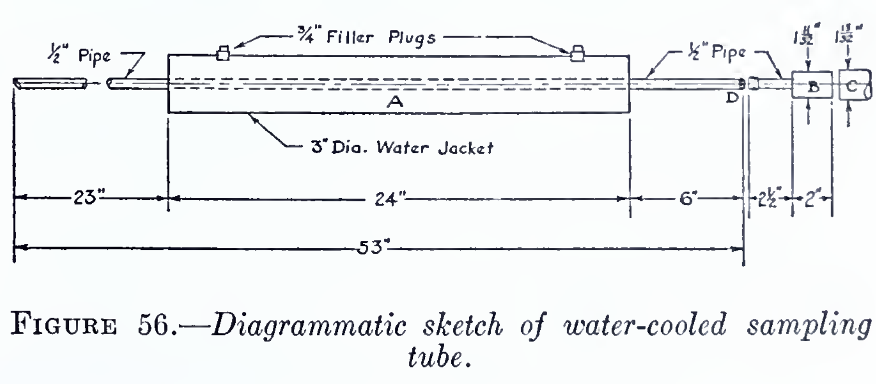

FIGURE 56.—*Diagrammatic sketch of water-cooled sampling tube.*

It was not necessary to circulate water in the outer jacket when the outside temperature was 50° F. or less, as a sufficiently large cooling area was provided.

Extra precautions were necessary at this point. Most of the stacks were constructed of steel and, in many cases, electrical equipment was grounded to these stacks. Therefore, some form of insulation was used to prevent direct contact of the aluminum tube with the metal sampling tube. Otherwise, there was the danger of an electrical shock to personnel and damage to equipment. In one instance the aluminum tube became welded to the steel stack.

Under certain sampling conditions where excessive moisture was encountered the electrostatic precipitator could not be used, because water condensed in the aluminum tube and caused arcing from the central electrode to the tube. In these cases, two Whatman No. 42 filter papers were used in a brass holder. This apparatus was also used ahead of the impinger and absorption tubes when it was desired to remove particulate matter. The holder used is similar to that described by Bayrer, et al. (*2*). As the material collected on the filter paper builds up, the resistance increases which reduces the air-flow. Therefore, the rate of flow was continuously measured with a rotameter.

Samples for total sulfur, sulfur dioxide, chloride, fluoride, and arsenic were collected in the standard all-glass impinger using a Willson pump as a source of suction. A volume of 175 milliliters of approximately 0.1N sodium hydroxide was employed as the collecting agent for all the above except sulfur dioxide. For the latter, a solution of 0.05N iodine plus potassium iodide in 5 percent sodium hydroxide was used; usually the volume was 100 milliliters measured accurately with a burette. These samples were titrated within a half hour after collection.

In order to determine whether chloride and fluoride were present in the gaseous or particulate state, the standard impinger and electrostatic precipitator were used in series. A holder was constructed to use the portable extension head of the electrostatic precipitator, which was connected to the air inlet tube of the impinger flask by means of a one-inch length of rubber tubing. The exhaust tube of the impinger was connected by about 15 feet of rubber tubing to a suction pump. All samples were taken at the rate of 1 cubic foot per minute. Phenolphthalein indicator was used to indicate that the alkalinity of the solution was not exhausted by acid gases.

Oxides of nitrogen were collected in a 550-milliliter flask by air displacement using an aspirator bulb. Ten milliliters of approximately 0.1N sulfuric acid and three drops of three percent hydrogen peroxide were added immediately after the sample was collected. The bottle was shaken vigorously and allowed to stand several hours to insure complete absorption of the gas in the liquid.

Samples for arsine and stibine were first collected in 250-milliliter, all-glass, gas washing bottles (fritted bubblers) using a 20 percent silver nitrate solution. It was found, however, that the pores in the bubbler soon became clogged due to dust and the precipitation of silver salts. Also, it was difficult to analyze for arsine and stibine in the same sample. Subsequently, it was decided to use a Folin, ammonia absorption bell fitted into a 250-milliliter, glass-washing cylinder containing 50 milliliters of 20 percent silver nitrate solution for arsine, and to collect a separate sample for stibine using 50 milliliters of 10 percent mercuric chloride. Collection rate ranged from 3 to 6 liters per minute, measured by a small rotameter.

Grab samples were collected in a number of stacks for the determination of carbon dioxide, carbon monoxide, oxygen and in some cases hydrogen. These samples were collected in 250-milliliter evacuated flasks. If appreciable quantities of particulate matter were encountered, filter paper was used to remove this material from the sample entering the flask.

In all stack samples collected, every effort was made to insure a representative sample. A glass tube, or the water-cooled sampling tube described previously, was inserted through the wall to the center of the stack. Wet clay or other material was used to seal the sampling tube into the stack to prevent dilution of the sample by the entrance of outside air.

Tests for carbon monoxide were made on the catwalks of the open hearth and blast furnaces and on the blast furnace casting floor with a colorimetric tube and aspirator bulb (*3*).

Qualitative tests for cyanides were made using a standard impinger containing a 1 percent ferrous sulfate, sodium hydroxide solution. Lead acetate papers were used to test for hydrogen sulfide in some stacks.

Air-flow measurements were made with the Alnor velometer, pitot tube with inclined gage, U-tube manometer or vane anemometer.

Nonindustrial Sources of Contaminants

Effluents from domestic heating equipment and the power plant of a boat were analyzed for the following constituents:

Carbon dioxide.	Sulfur.
Carbon monoxide.	Chloride.
Oxygen.	Fluoride.

Sampling equipment and methods were similar to those used for sampling the plant stacks. However, it was necessary to use a portable electric generator.

A ⅜-inch copper tube was used in collecting samples from the boat and domestic stacks. The copper tube was connected to the electrostatic precipitator by a rubber stopper which was inserted in the end of the precipitator tube.

Sampling in General Atmosphere

The low concentrations of airborne contaminants and the wide variety of weather conditions found while taking samples outdoors necessitated the development of a very specialized technique. During the period that samples were taken, air temperatures varied from 18° to 81° F. Snow, sleet, and rain were frequent at the beginning of the study. Wind speed varied from 0 to 30 miles per hour.

Collection methods and apparatus.—Two automobiles were equipped as mobile laboratories. Gasoline driven electric generators, capable of generating 500 watts at 110 volts a. c., were used as a power source; the generators were located in the trunks of the cars. This equipment provided sufficient power to operate simultaneously the electrostatic precipitator, the standard impinger pump, and a light source for the analytical work. The rear seat of the car was removed and the space converted into a miniature laboratory. This equip-

DONORA STUDY

ATMOSPHERIC SAMPLING DATA

DATE 2-22-49 TIME 3:20 PM

Sampling Location # 4

WEATHER DATA

Wind Direction West Wind Speed 3 mph

Wet Bulb 53°F Dry Bulb 56°F Rel. Hum. 83%

Illuminometer Readings 500 Turbulence Slight

General Weather: Rain Snow Sleet Cloudy P. Cloudy Sunny

Smoke Behavior: Gradually rising and blowing over hills

Remarks: Hazy, two trains passed during sample

SAMPLES

A. SO_2 Determination

Ml I_2 used Vol = 1200 liters

F 49.62
I 0.48

49.14 x 0.484 = 23.78 ml thio

Thio used I_2 lost

F 26.04
I 3.88
22.16

I 23.78
F 22.16
1.62
Blank -0.10
1.52

ppm SO_2 = $\frac{1.52 \times 0.32 \times 382}{1200}$ = 0.155 ppm SO_2

B. Total S. Lab # 746
Vol = 1280 liters Analysis

C. Electrostatic precipitator Lab # 747 Tube = 27
Vol = 183 ft^3
Analysis: Total fume Cd
Zn Pb

D. Halogens Lab # 748 Vol = 60 ft^3
Analysis: Cl
F

E. Other Oxides of Nitrogen
Lab # 749

FIGURE 57.—*Atmospheric sampling data form showing sampling data and calculations.*

ment was used for sampling regularly at twelve selected stations. Samples were collected in the standard impinger for sulfur dioxide, total sulfur, chloride, and fluoride; and in the electrostatic precipitator for total particulate matter, zinc, lead, and cadmium. Periodically samples were also collected for oxides of nitrogen, carbon monoxide, and hydrogen sulfide. Figure 57 shows a form used for recording the data.

The wind direction, during each 2-hour sampling period, was determined several times by the use of a smoke tube and a compass.

Wind speed was determined by a direct-reading cup anemometer, which was observed at intervals during the entire sampling period. The range of wind speed was noted and an estimate made of the average speed.

The wet and dry bulb temperatures were taken by means of a bulb psychrometer.

Other sampling equipment consisted of a suction pump, standard all-glass impingers, electrostatic precipitators and rotameters.

Samples for the determination of sulfur dioxide and for total sulfur were taken in the all-glass impinger using 0.005N iodine containing 0.5 percent sodium hydroxide. A volume of 50 milliliters of this solution, measured accurately with a burette, was placed in each of two impingers. Distilled water was added until the solution level reached the 100-milliliter mark in order to insure a sufficient depth of liquid above the impinger plate. Two impingers were connected in parallel and samples were collected simultaneously for sulfur dioxide and total sulfur. The samples were taken for 1 hour at a sampling rate of about 24 liters per minute, a rotameter being used to measure the rate of flow for each impinger. A common household electric heating pad was used to prevent freezing of the sampling medium during low temperatures. The impingers were covered to prevent the sunlight from affecting the results of the sulfur dioxide determinations.

The samples for sulfur dioxide were titrated immediately after collection using 0.01N sodium thiosulfate with starch as an indicator. A sample calculation is shown on the sample form. The value 0.484 is the milliliter of thiosulfate equivalent to 1 milliliter of iodine. The value 0.32 used in the calculation is the weight in milligrams of sulfur dioxide equivalent to 1 milliliter of the thiosulfate solution. The blank used in the calculation was determined by the regular sampling procedure in sulfur dioxide free air.

In order to insure a stable sampling medium, 4 liters of the iodine solution were made at a time and allowed to stand at least 2 days until no color remained in the solution.

A Thomas recorder (*4*) was used at five of the sampling locations to obtain a continuous conductivity record calibrated for sulfur dioxide. The instrument was mounted in a panel truck and was stationed for 1 week at a time at sampling locations Nos. 1, 2, 4, 5, and 6. Other continuous recording instruments within the truck were used to record barometric pressure and temperature.

The sampling rate of the electrostatic precipitator was determined by means of a glycerine manometer, and was maintained at 3 cubic feet per minute for a period of 2 hours. During the "test period," 6- to 12-hour samples were taken at sampling location No. 9 throughout the day and night.

The samples for the determination of chloride and fluoride were taken in a standard all-glass impinger using 100 milliliters of 0.1N sodium hydroxide as a sampling medium. The sampling rate was 1 cubic foot per minute for 1 hour. Samples for halogens were also taken at sampling locations Nos. 4 and 9 in two fritted bubblers, in parallel arrangement, for 5 to 12 hours at a combined rate of about 1 cubic foot per minute measured by a rotameter. The samples were combined for analysis. It was necessary to add additional liquid at intervals during warm, dry days.

Samples for the determination of oxides of nitrogen were collected in standard 4-liter bottles by air displacement with a suction pump to obtain approximately 15 air changes. Immediately afterward, 20 milliliters of 0.1N sulfuric acid and 5 drops of 3 percent hydrogen peroxide were added to the bottle, and it was shaken vigorously. Samples were transferred with distilled water after a minimum of 4 hours standing during which time they received occasional shaking.

DETERMINATION OF CONTAMINANTS[2]

For the purposes of this study a wide variety of chemical methods of analysis was required to make all of the necessary determinations upon the samples submitted to the laboratory. It is deemed pertinent to this report that some abbreviated description of the methods used be given for the benefit of persons especially interested in this phase of the study. The methods employed are briefly mentioned with references to the literature and are grouped according to the constituent determined rather than by type of sample. When more than one constituent was determined on a single sample, separate aliquots were taken for each such determination.

Sulfur

In the various samples, sulfur occurred principally as sulfite, sulfate or sulfide. The sulfide occurred mostly in bulk material samples and in dust samples collected by electrostatic precipitators or filter papers. The sulfide and sulfite were converted to sulfate by oxidation with bromine or nitric acid according to the type of sample. The total sulfate was then determined by precipitation with barium chloride. When the sulfate concentration was very low a modified turbidimetric procedure (*5*) was used. This involved precipitation of the barium sulfate under carefully controlled conditions and stabilization of the suspension with a glycerine-alcohol mixture. Measurement of the turbidity was made photoelectrically at 500 millimicrons by a Coleman Model 11 spectrophotometer. Test tubes with a light path of 25 millimeters were used as the cells. Tests of the precision and accuracy of the method with the use of prepared known concentrations were satisfactory. High concentrations of sulfate were determined by the common gravimetric procedure. Intermediate concentrations were checked by both procedures.

Oxides of Nitrogen

Atmospheric and stack gas samples for determination of oxides of nitrogen were collected by air displacement through a clean dry bottle. Sulfuric acid and hydrogen peroxide

[2] By Dohrman H. Byers.

were added to absorb and oxidize the oxides of nitrogen. After a suitable period, during which the bottle was repeatedly shaken, the sample was rinsed into a pyrex bottle and sent to the laboratory. The oxides of nitrogen were determined colorimetrically by the phenoldisulfonic acid method (*6*). The color was measured at 410 millimicrons by the Coleman spectrophotometer and the nitrogen concentration read from a standard curve.

Chloride

Stack gases and the general atmosphere were sampled for the presence of chloride. Most of the samples were collected in 0.1N sodium hydroxide in standard impingers. Chloride was also determined in particulate matter collected by the electrostatic precipitator and filter papers, and in bulk materials. In a few samples it was necessary to distill the chloride as hydrogen chloride into dilute ammonia solution before determination. All samples were determined by means of the Mohr titration with the use of a yellow light to view the end point.

Fluoride

Samples for the determination of fluoride were collected in the same manner as those for chloride. In most instances the same samples were aliquoted for the two determinations. The fluoride was distilled from sulfuric acid as the fluosilicic acid and caught in alkali. The fluoride was measured colorimetrically with a thorium-alizarin reagent by visual comparison with standards in Nessler tubes after the method of Talvitie (*7*).

Arsenic

Determinations of arsenic were made upon bulk materials and upon dust and fume samples, collected both by the standard impinger and by the electrostatic precipitator. Atmospheric samples for arsine were collected in silver nitrate solution in petticoat bubblers. Arsenic in these various types of samples was reduced to the trivalent state with hydrazine sulfate and distilled as arsenic trichloride. The distillate was oxidized and treated with hydrazine sulfate-ammonium molybdate reagent (*8*) for the formation of the molybdenum blue color. The color was measured at 840 millimicrons by the Coleman spectrophotometer and the arsenic concentration read from a standard curve.

Antimony

Stibine was collected in bubblers containing mercuric chloride solution. The antimony was oxidized to the pentavalent state with ceric sulfate. Rhodamine B reagent was added and the red compound formed with antimony was extracted in benzene and compared colorimetrically with similarly prepared standards (*9*).

Lead

Atmospheric samples, collected with the standard impinger, electrostatic precipitator, and filter papers, were analyzed for lead by colorimeteric determination with dithizone (diphenylthiocarbazone) in chloroform (*10*). The method is a double extraction procedure using citrate and cyanide to suppress interference. For the final measurement the mixed color was read at 510 millimicrons with the Coleman spectrophotometer and the lead concentrations were read on a standard curve.

In the bulk samples the lead concentrations varied greatly. The low concentrations were determined by the foregoing dithizone method after a separation from interferences by a sulfide precipitation and re-solution. The high lead values were determined gravimetrically as lead sulfate.

Cadmium

The procedure of Setterlind and Krause (*11*) was slightly modified and used for the determination of cadmium in the atmospheric and stack gas samples. It was likewise used for low concentrations of cadmium in the bulk materials. This is a single-color method. After two extractions from alkaline solution, the first with cyanide present, the cadmium is stripped from the chloroform layer with acid. The green color of the dithizone which was combined with the cadmium remains in the chloroform layer. This color was measured at 610 millimicrons in a Beckman DU spectrophotometer and the cadmium concentration read from the standard curve.

In several bulk samples the cadmium concentrations were very high and were determined by electrodeposition of the cadmium from a cyanide solution (*12*).

Zinc

A colorimetric method (*8*) employing dithizone in carbon tetrachloride solution was found applicable to the determination of zinc in the atmospheric and stack gas samples. This method was also used for traces of zinc in certain bulk samples, after a separation of the zinc by sulfide precipitation and re-solution. The method is a single extraction procedure in a solution carefully buffered at pH 4.7 in the presence of an exactly controlled concentration of sodium thiosulfate. The mixed color of the carbon tetrachloride extract was measured at 535 millimicrons by means of the Beckman DU spectrophotometer.

Most of the bulk samples contained zinc as a major constituent; therefore, the determination was made gravimetrically by the precipitation of zinc sulfide and a final ignition to zinc oxide.

Iron

Some of the fume samples collected with the electrostatic precipitator were analyzed for their iron content. The material was brought into solution with hydrochloric acid and any residue was fused with potassium bisulfate. The iron was separated by a triple precipitation from ammoniacal solution. The final precipitate was dissolved in hydrochloric acid, and the iron was reduced by excess stannous chloride solution. The excess reducing agent was oxidized with mercuric chloride and the ferrous iron titrated with standard potassium dichromate (*13*).

A few samples of air were taken in evacuated flasks to be analyzed for possible iron carbonyl content. Strong sulfuric acid was introduced into the flasks and the samples allowed to stand to dissolve any iron carbonyl. This solution was treated with carbon tetrachloride and bromine water and

then taken to fumes of sulfuric acid. Nitric and perchloric acid were added and fumed off. The final solution was treated with permanganate and finally the iron was precipitated with ammonia solution, a small amount of aluminum chloride having been added as a collector. The precipitated iron was redissolved, then determined colorimetrically by the potassium thiocyanate method (*6*).

Manganese

The determination of manganese in the fume samples was made upon the filtrate after the precipitation of iron with ammonia solution. The manganese was converted to permanganate ion by oxidation with potassium periodate (*14*). The color was then visually compared in Nessler tubes with a series of similarly prepared standards.

Acid Gases

Acid gases were collected in standard alkali with impingers or bubblers. This solution was titrated in two steps with standard acid using phenolphthalein and methyl orange as the indicators. From these titrations the carbon dioxide and other acid gases were calculated.

Total Particulate Matter

The total weight of particulate matter of each sample collected with the electrostatic precipitator was determined by direct weighing of the collecting electrode before and after removal of the material for chemical analysis. The external surface of the electrode was cleaned with 95 percent ethyl alcohol then wiped with a clean, dry gauze pad. The tubes were allowed to stand in the balance room for 15 minutes to reach an equilibrium with the atmosphere before weighing. The particulate matter was then removed from the inner surface of the electrode by washing with either 95 or 30 percent ethyl alcohol and rubbing with a rubber policeman. A few very resistant deposits were removed with 1:1 nitric acid. After all the samples were removed, the interior of the electrode was rinsed with water and alcohol then wiped dry by forcing a wad of clean gauze through the tube. The exterior surface was again cleaned and dried and the tube reweighed in the same manner as previously described. The difference in the two weighings was reported as weight of total particulate matter (*15*).

Insoluble Solids

Some samples collected in the standard impinger, particularly stack gas samples, had appreciable residues insoluble in the collecting media. These were filtered on asbestos in weighed Gooch crucibles and dried at 110° C. The crucibles were reweighed to obtain the weight of the dried solids by difference. The samples were then ignited to burn off carbonaceous materials and, after cooling, re-weighed to determine the loss on ignition.

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Evaluation of Plant Effluents

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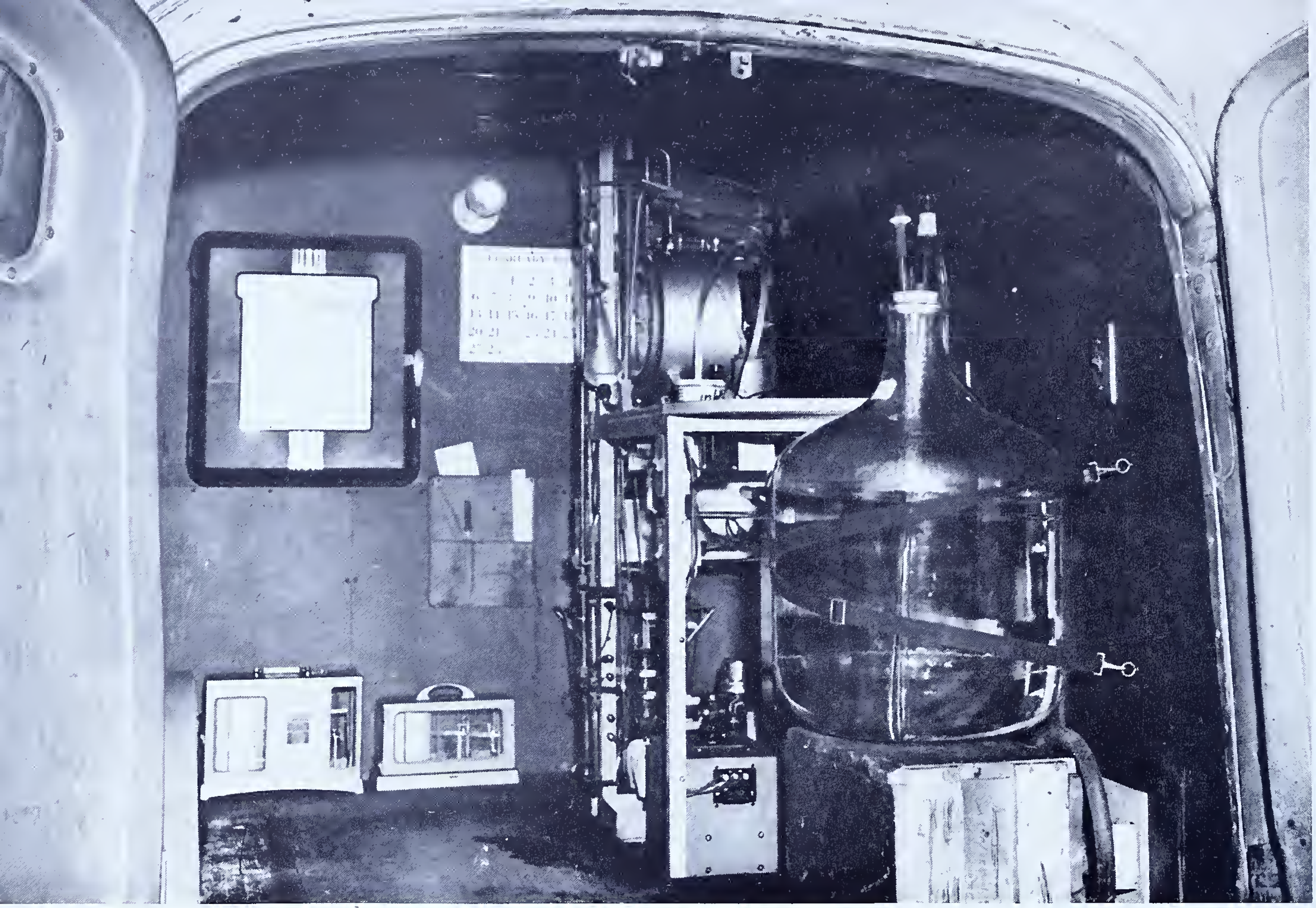
DESCRIPTION OF ZINC PLANT OPERATION

Figure 58 is a flow diagram of zinc plant operations. The numbers in circles refer to the locations at which bulk samples were collected. An analysis of these samples will be given in a subsequent report.

Roasters

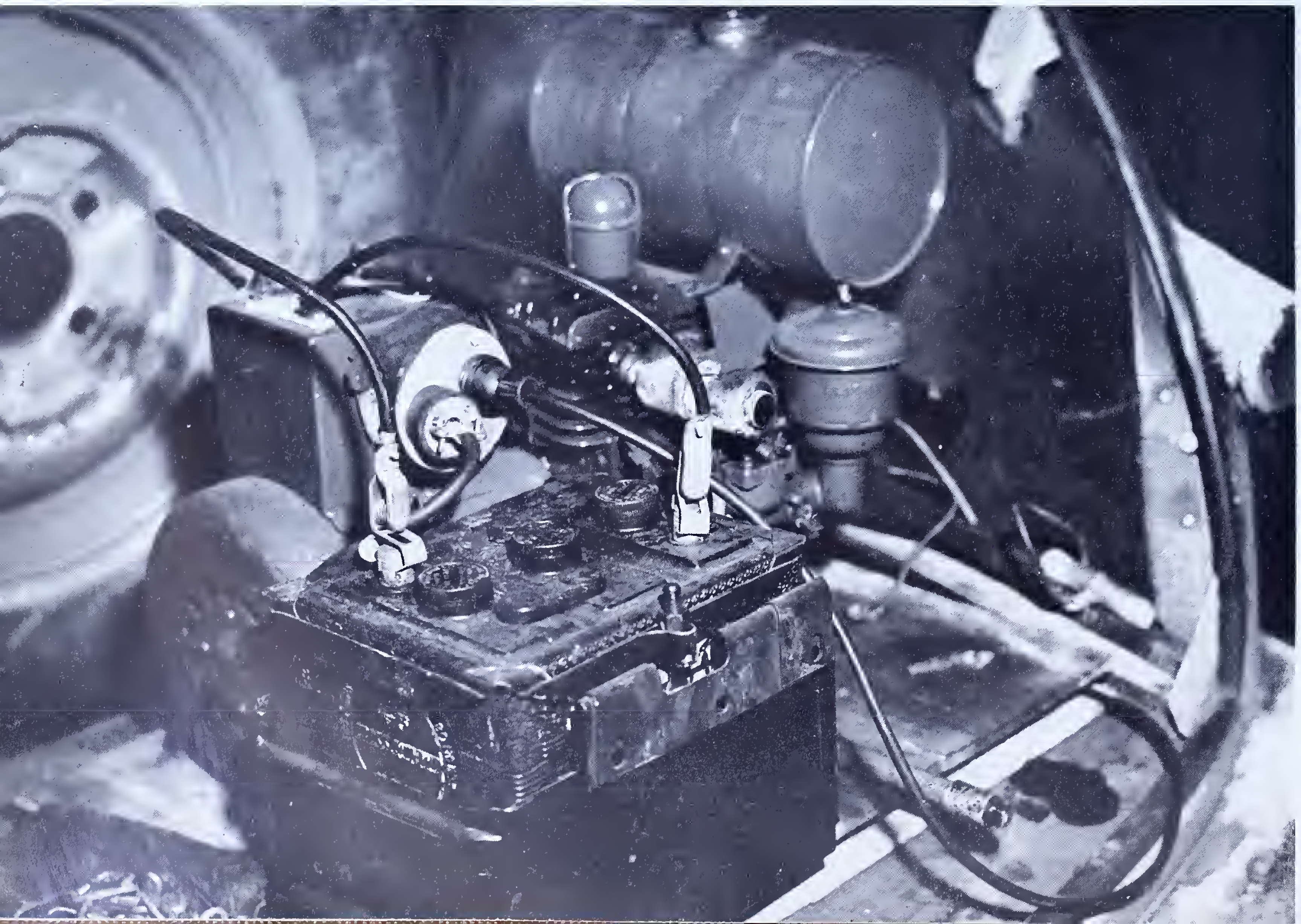
Zinc sulfide concentrates, containing approximately 60 percent zinc and 30 percent sulfur, are dried in a gas-fired Ruggles-Coles rotary dryer to reduce the moisture content from about 4 to 1 percent. Flotation ore, or fine concentrates, are dried to 1 percent moisture in an externally gas-fired revolving type dryer. Coarse concentrates are crushed

Photographs taken from same point at same time of day showing comparison of atmospheric pollution on different days.



Below, Gasoline-driven generator in trunk of car used as power source in the field collection of air samples.

Above, Automatic sulfur dioxide recorder in truck.



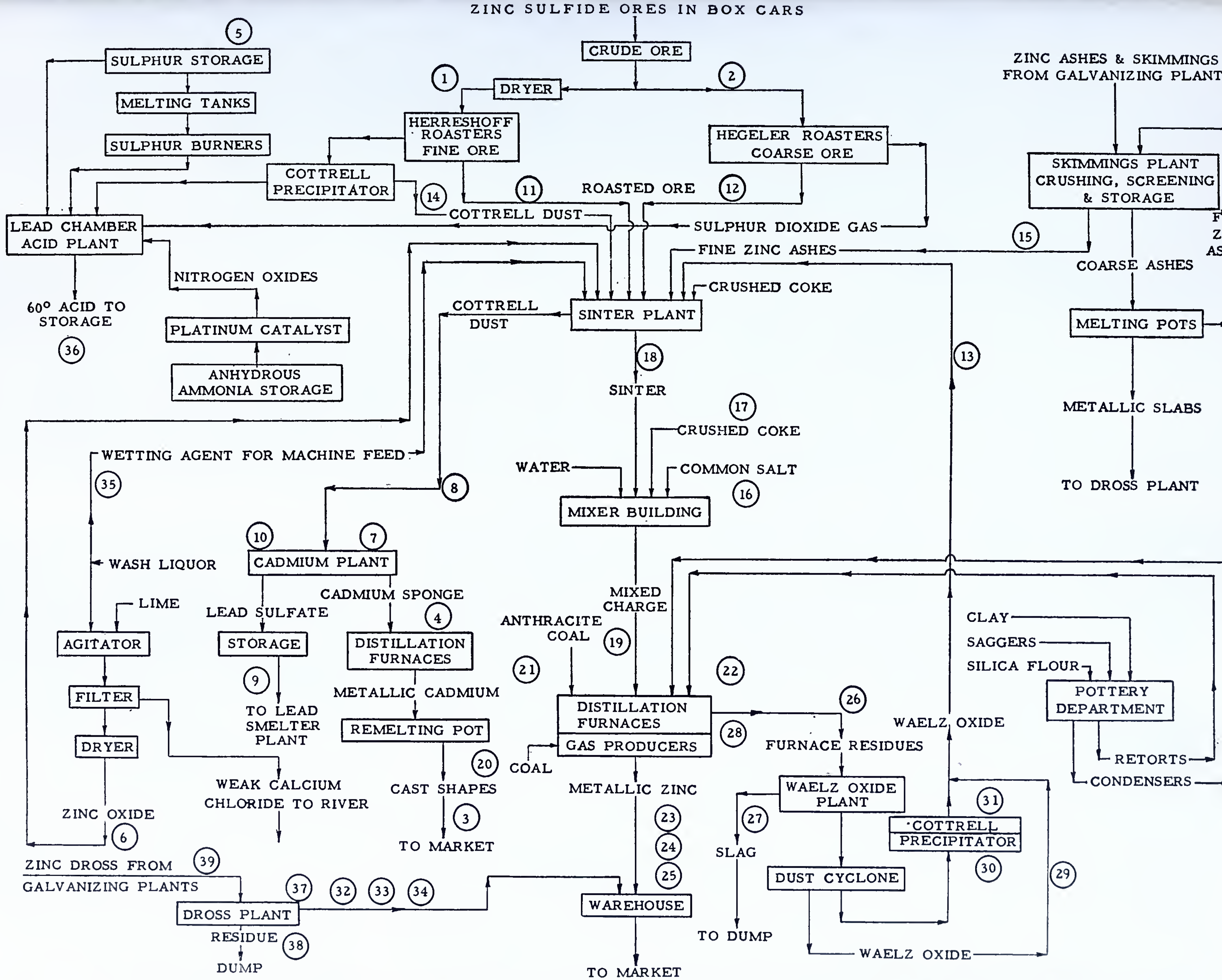


Figure 58.—*Flow diagram—The zinc plant. Numbered circles indicate locations at which bulk samples were collected.*

and screened to minus 14 mesh. The flotation ore and all fine concentrates from the coarse ore are fed into Herreshoff roasters and the coarser ore is roasted in Hegeler furnaces.

The first step in the metallurgy of zinc ore is the replacement of sulfur in zinc sulfide with oxygen. This is accomplished by roasting which reduces the sulfur content from about 30 to 3 percent. There are two types of roasters in use at the zinc plant—(1) the Hegeler furnaces and (2) the Herreshoff, or circular furnaces.

The Hegeler furnace is rectangular and consists of seven hearths, one above the other. Natural gas is burned in separate chambers under the three bottom hearths to supply additional heat for the reaction. The products of combustion are vented to the atmosphere through ducts which are connected to the large hoods at each end of the furnace. Ore is fed onto the top hearth and is raked, about once an hour, onto the next lower hearth. Raking is done from alternate ends of the furnace to obtain a more uniform distribution and heating of ore on the hearths. The hot gases containing the sulfur dioxide are drawn off at the center of this furnace and flow through large flues into the Glover tower of the sulfuric acid plant.

The Herreshoff furnace consists of 14 shelf-type hearths with mechanical rakes. Fine concentrates and the ore, less than 14-mesh, are fed in at the top of the furnace. The mechanical rake spreads the dried ore evenly over the top shelf and gradually pushes the material toward the perimeter, where it drops onto the next lower shelf. The ore is then gradually pushed toward the center of the furnace on the second shelf and falls on the third shelf where it is raked to the outer edge and continues in this manner to the bottom of the furnace. Natural gas is burned at the bottom of the furnace to supply additional heat for the reaction and the hot gases flow upward countercurrent to the flow of ore. As the ore flows downward, it is gradually ignited and combustion of sulfur to sulfur dioxide takes place. The hot gases containing sulfur dioxide are drawn off at the top of the furnace through large flues, pass through Cottrell precipitators to remove suspended dust, and enter the Glover tower for the production of sulfuric acid.

Sinter Plant

The roasted product, "Calcine," is transported to the sinter plant where it is mixed with coke, other high grade zinc materials, and "wash liquor" for sintering. The purpose of the sintering process is to agglomerate and densify the structure of the roasted ore and other zinc material; to remove the bulk of residual sulfur; and to remove the lead, cadmium and rare metals. Some zinc compounds are driven off at this point either by volatilization or mechanical action.

Sintering equipment consists of two Dwight-Lloyd machines, each 42 inches wide and 33 feet long, together with auxiliary equipment such as fans, mixers, crushers, screens, and storage bins.

Raw materials for the sintering process include roasted concentrates, Waelz oxide, washed oxide from the cadmium plant, and minus 10-mesh galvanizers ashes. These materials are fed from storage bins at a predetermined rate onto a belt conveyor together with a small amount of crushed coke which serves as the principal fuel for the process. Residual sulfur in the roasted concentrates also furnishes a small amount of heat. This belt conveyor discharges into a pug mill where water and "wash liquor" from the cadmium plant are added to moisten the mix. The pug mill discharges through a chute onto grate bars supported by moving pallets on the sinter machine. Ignition of the mixed charge is started with natural gas burners located about 6 inches above the bed and at the feed end of the machine. As the pallet moves along the frame of the sinter machine, air is drawn down through the bed by means of large fans. Sintering action is complete by the time the pallet reaches the end of the machine, and the pallet dumps its load into the discharge hopper.

The sinter is then transferred to a crusher and screens by means of buckets and an overhead crane. The plus ⅝-inch size of sinter is returned to the machine to serve as hearth layer on the grate bars. The minus ⅝-inch size material is sent to the mixer house storage bins.

The gases, fume, and dust from the sinter machines are forced through five Cottrell precipitator units for collection of dust and fume. The gas stream, containing sulfur dioxide, cadmium, lead, and zinc, in the form of chloride, sulfate, sulfide, and sulfite, is conditioned by the addition of live steam which enters ahead of the Cottrell units. The main gas stream from the sintering machines is divided in the precipitator building so that a portion passes through two Cottrell units and the other portion through three Cottrell units. The effluent from these units is vented to the atmosphere through two stacks 4 feet (I. D.) in diameter and approximately 110 feet high.

Zinc Spelters

Distillation equipment consists of 10 horizontal retort type furnaces, called spelters (only 9 of which were in use at the time of this study), each containing 304 clay retorts per side or 608 retorts per furnace. No. 1 zinc spelter, similar to the other 9 distillation furnaces, is used entirely for reclamation of zinc from high grade furnace residues. Heat is supplied by combustion of producer gas from two producers located at one end of each furnace. Combustion air enters the furnace through 4 vertical ports at each of 19 locations on each side of the furnace. The hot gases pass over the outside of the retorts and leave the furnace at the opposite end from the gas producers. These gases pass through a waste heat boiler and thence to the atmosphere through a stack 5.5 feet (I. D.) in diameter, and approximately 125 feet high. Steam injectors, with additional natural gas burners, were installed early in 1949 in each waste heat boiler to afford more complete combustion of the gases and thus reduce the amount of soot entering the stacks.

The daily furnace routine consists of cleaning retorts and condensers, charging retorts with the mixed charge, and resetting condensers in each retort. This operation begins about 6 a. m. and is completed by 10 or 10:30 a. m.

The charge for the furnaces, commonly called the "mixed charge," is prepared in the mixer house where definite quantities of sintered material, coke and salt are weighed and thoroughly mixed in a large mixer. Sufficient water is added to dampen the mixture. The mixed charge is placed in furnace charge cars and taken to the furnaces in the afternoon.

After the retorts are charged, a clay condenser shaped like the frustum of a cone is placed in the open mouth of the retort and the junction sealed with dampened, finely ground, anthracite coal. The small end of the condenser is closed with this coal but not sealed too tightly in order to permit emission of gases through the seal. Each side of the furnace is charged in sections. When the material inside the retorts reaches a certain temperature, gases escape from the condenser mouth and are ignited. Carbon monoxide is burned to carbon dioxide. Theoretically, it is simple to reduce zinc oxide to metallic zinc vapor in the presence of carbon and salt, and under proper temperature conditions. The actual reactions which take place inside the retort are quite complex and many side reactions occur which tend to form zinc oxide or zinc dust instead of molten zinc. The presence of salt in the charge tends to reduce these side reactions.

Zinc metal is drawn from each condenser three times during the 24-hour cycle. The first draw begins in one section of the furnace at about 3 o'clock in the afternoon. A small hole is made through the coke in the lip of the condenser and the molten metal flows into a pot whence it is cast into slabs. After the metal has been drawn, the condensers are sealed with coal and distillation continues until about midnight when a second draw is made. The third and final draw is made early the following morning after which the cycle is repeated.

Zinc byproducts produced in the process which are too low in zinc content for retreatment in the retort furnaces, broken condensers and other residues low in zinc are sent to the Waelz plant for recovery of zinc and other metals. Scrapings from condensers and zinc metal which were spilled on the floor are charged into retorts at one end of each furnace. Approximately 21 percent of the retort capacity is used for retreatment of these richer furnace byproducts.

Pottery Department

The retorts and condensers used in the zinc smelting furnaces are manufactured in the pottery department. High quality clay, crushed saggers (broken retorts and condensers), and silica flour are thoroughly mixed in proper proportions with water and extruded into rectangular pieces and allowed to age. After aging, the sections are mixed in a pug mill, shredded and de-aired before extrusion as a slug. This slug is placed into the retort press and the retort section is extruded under high pressure. Retorts are dried for 40 days in a gas-fired kiln and are then fired in kilns adjacent to distillation furnaces at approximate furnace temperature prior to placing in the furnaces.

Condensers are made in a similar manner and are dried and fired prior to use.

Waelz Plant

The function of this operation is to process low grade zinc byproducts. The impure zinc oxide produced in this operation is returned to the sintering process and again passes through the smelting cycle.

Furnace residues, used condensers and other low grade zinc byproducts are mixed in a pug mill and forced into a rotary brick-lined kiln, 120 feet long and 9 feet in diameter. The slope of the revolving kiln carries the material through the kiln and the unburned coke in the furnace residues supplies sufficient heat to carry out the same type of reaction as explained for the distillation furnaces. As the metallic zinc vapor is released from the slag body, it is immediately converted to zinc oxide by the oxidizing atmosphere in the kiln. The suspended zinc oxide and other dust is passed through two waste heat boilers, a cyclone dust collector, Cottrell precipitator units and thence to the atmosphere through a single 125-foot stack. A fan located at the base of this stack provides the necessary air-flow through the kiln, boilers, and Cottrell units. Slag from this process contains about 1½ percent zinc.

Byproduct Processes

Galvanizers byproducts are received from outside sources and consist of zinc ashes, skimmings, and dross.

Zinc dross is an iron-zinc alloy containing 94 percent zinc. It is obtained from the bottom of galvanizing baths and is melted in cast iron pot furnaces, and when molten, is transferred to large gas-fired graphite retort furnaces for distillation of zinc. Ten of these retorts are located in a separate building adjacent to the Waelz plant. The retorts are tapped periodically and molten zinc is poured into slabs. Residues from these retorts contain a high percentage of iron and are usually discarded.

Zinc ashes and skimmings from galvanizing baths contain approximately 70 percent zinc as the oxide, along with ammonium chloride and other impurities. This material is crushed and screened in a separate building. The coarse material from the screens contains metallic zinc which is melted in pots and recovered in slab form for redistillation in the dross plant. The fine zinc ashes are mixed with roasted concentrates and pass through the sintering machine.

Flux liquor and zinc oxide were formerly intermittently reclaimed from zinc skimmings in the cadmium plant. However, this process was not in operation during the survey. A brief description of the process is included under a description of the cadmium plant.

Acid Plant

Sulfuric acid is made by the lead-chamber process. The plant consists of 6 separate units, each of which is composed of 1 Glover tower, an ammonia converter, 10 lead chambers, 2 Gay-Lussac towers, and 2 fans. Each stream of sulfur dioxide entering the acid plant remains separate throughout the acid process. Three of the acid plants are supplied from the two Herreshoff roasters; two units from the Hegeler furnaces and one unit from a sulfur burner. Sulfur dioxide to supplement that from the roasters is supplied by burning sulfur directly in the Glover tower feed line.

The hot roaster gases and sulfur dioxide from burners enter the base of the Glover tower, which is the beginning of the conversion of sulfur dioxide into sulfuric acid. Nitrogen oxides (made by catalytic conversion of anhydrous ammonia on a heated platinum gauze, for conversion of sulfur dioxide to sulfur trioxide) are introduced in the Glover tower. The flow of acid is countercurrent to the flow of gases. The gases then pass into the lead chambers. Steam or water or both are introduced in the form of sprays located

in the roof of the chambers. The complex reactions of the chamber process take place and weak chamber acid is condensed. Gases leaving the lead chambers are drawn through two masonry packed Gay-Lussac towers countercurrent to the flow of cooled strong acid for absorption of nitrogen oxides not used in the process, after which the gases are discharged to the atmosphere through six 30-inch (I. D.) in diameter lead stacks, approximately 75 feet high. These gases contain oxides of nitrogen and acid mists.

Cadmium Plant

Cottrell precipitator dust and fan scrapings from the sinter plant are brought into the cadmium plant in buckets holding 2 to 3 tons. This material consists essentially of chlorides of zinc and cadmium, sulfates of zinc and lead, with sulfides and sulfites of these elements. The dust is dumped into a circular tank containing sufficient water to cover it. Sulfuric acid and sulfuric acid plant sludge (zinc sulfate, lead sulfate, and weak acid) are added. The mixture is heated with steam, for 4 to 10 hours depending upon certain conditions. There are four sulfating tanks which are connected to two natural draft stacks.

Cadmium, zinc, rare metals, and traces of lead become soluble in the sulfating tanks. The mixture is agitated, allowed to settle, and the supernatant liquid is pumped into one of two purification tanks. The sludge (lead sulfate) in the sulfating tanks is removed and allowed to drain then stored and sold to an outside concern. The two purification tanks are each connected to a single natural draft stack. A small amount of zinc dust is added to reduce acidity and precipitate most of the rare metals and some cadmium. The precipitate is allowed to settle and the supernatant liquid from both (or one as the case may be) tanks is pumped into the precipitation tank. The sludge in the purification tanks is allowed to accumulate and eventually stored out of doors to dry. Rare metals are recovered from this sludge on an experimental scale.

The supernatant liquor from purification tanks is treated with zinc dust in the precipitation tank to reduce the acidity and precipitate cadmium as a sponge. The sponge is allowed to accumulate in the tank and is then pressed into briquettes by means of a hydraulic press. The supernatant liquor from the precipitation tank is pumped into two large settling tanks where a small amount of zinc dust is sometimes added to precipitate additional cadmium.

After most of the cadmium has been precipitated from this solution, the liquor is pumped to storage tanks where a portion is sent to the sintering plant and the balance is treated with lime slurry to reclaim zinc. The precipitated zinc hydroxide is allowed to settle, then filtered, and the filter cake is fed by screw conveyor to a small gas-fired Herreshoff furnace where the zinc hydroxide is converted to the oxide.

The briquetted cadmium sponge is fed into one of four horizontal gas-fired furnaces (charged about every 16 hours). The cadmium is distilled in retorts which are tapped periodically. Hoods over each furnace exhaust most of the gases and cadmium fumes during normal operation. These are connected to a single duct leading to a cyclone, bag collectors in series, and then through the exhaust fan to the outside.

Ordinarily the pigs of cadmium from the first distillation are recharged into the retorts for a second distillation, sometimes a third. The insoluble residues are removed from the furnaces about every 16 hours and are retreated in the Waelz plant. Furnace residues are mixed with incoming dust and are retreated in the cadmium plant.

The pigs are placed into a melting pot and are subsequently cast into balls, pencils, or other forms. The melting pot is exhausted by a small slot exhaust connected to the main exhaust system from the furnaces.

Flux Liquor Plant

Zinc skimmings are processed in the cadmium plant building for reclamation of zinc, lead, and other materials. The skimmings consist essentially of metallic zinc, zinc oxide, zinc chloride, and ammonium chloride.

This material is wet ground in a ball mill and is passed through a classifier to separate the solids from the liquid. The material is then passed over a Wilfley table to separate zinc oxide and metallic zinc. The slurry from the classifier flows to an agitator and thence through a filter. The filtrate, containing ammonium chloride, zinc chloride and water, is concentrated and later sold as a galvanizing flux. The filter cake, consisting essentially of zinc oxide, water and zinc chloride, is mixed with a lime slurry to precipitate the zinc chloride as zinc hydroxide. After settling, the sludge is filtered and the filter cake of zinc hydroxide is converted to zinc oxide. This then enters the process again at the sintering plant.

The reclamation of zinc and flux liquor from zinc skimmings was not in operation at the time of this study. It is normally an intermittent operation and is a wet process. The only contaminant escaping is possibly ammonia in very small concentrations.

DESCRIPTION OF STEEL PLANT OPERATION

In this brief description of operations, the steel plant is divided into the five following departments: (1) Blast furnace, (2) open hearth, (3) blooming and billet mills, (4) rod mills, and (5) wire mill. A flow diagram of the operations is shown in figure 59.

Blast Furnace

Pig iron for the open hearth department is produced in two blast furnaces designed to provide 1,450 tons of hot metal daily. The furnaces are dimensionally the same, approximately 110 feet high and have a hearth diameter of 18 feet 6 inches.

Raw material requirements for a normal day's operation are 45 carloads of iron ore, 40 of coke, 6 of limestone, and 6 of miscellaneous materials such as sintered flue dust, open hearth slag, iron, and steel scrap. The normal air requirement for each furnace is 42,000 cubic feet per minute, and is supplied by five vertical blowing engines. The air used must be preheated; this is accomplished by its passage from the blowing engines through four stoves for each furnace. These stoves are heated by gas, produced in the blast furnace,

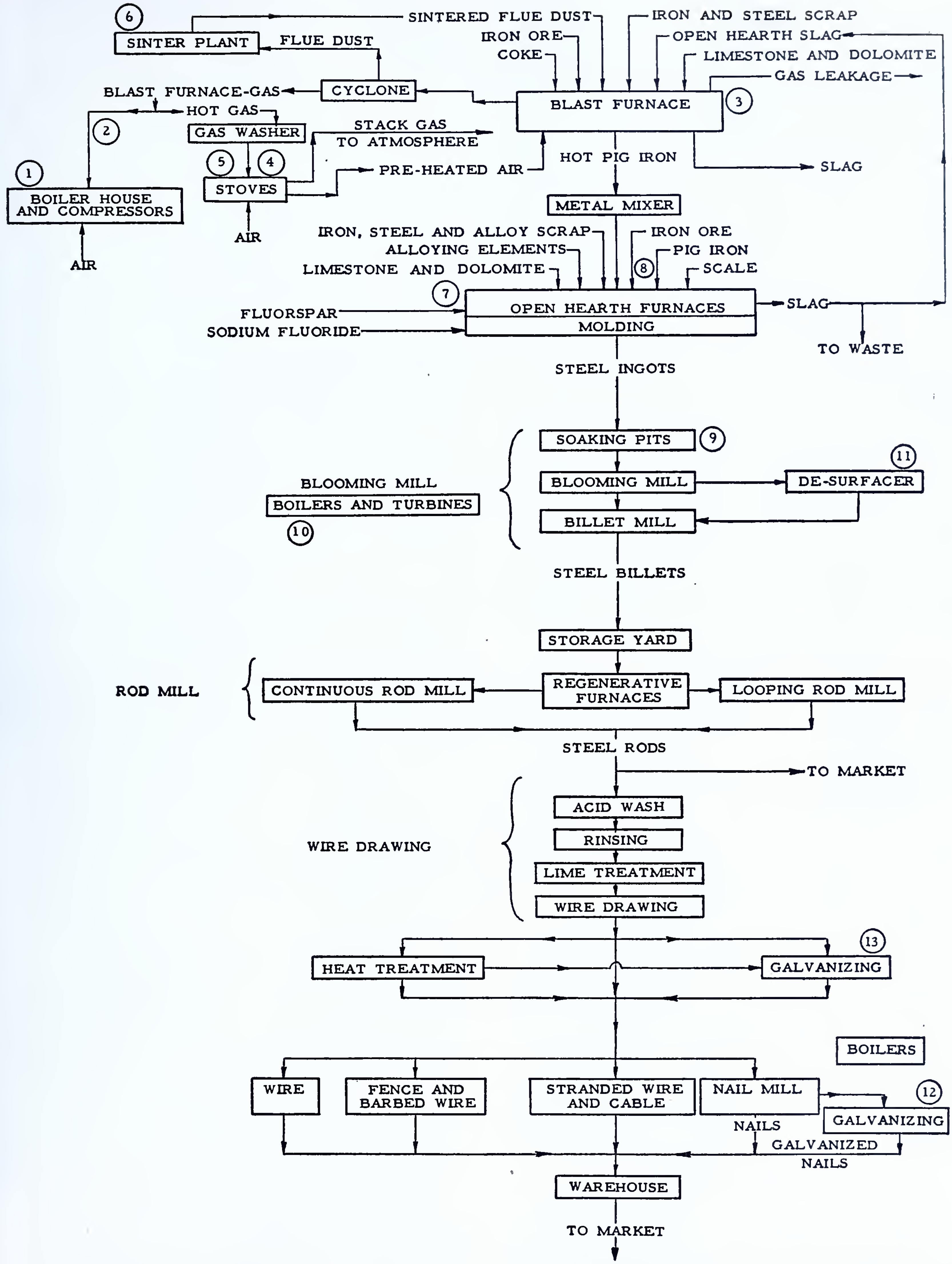


Figure 59.—*Flow diagram—The steel and wire plant. Numbered circles indicate locations at which stack samples are collected.*

which is precleaned by passage through a series of dust collectors and gas washers. Each blast furnace produces about 120,000 cubic feet per minute of blast furnace gas; each set of stoves uses 20,000 cubic feet per minute or a total of 40,000 cubic feet per minute. The products of combustion from the eight stoves are discharged to the atmosphere through a single stack 10 feet in diameter and 175 feet high. The balance of the blast furnace gas is used in 16 boilers to provide steam for auxiliary equipment. Since the steam load is not constant, some blast furnace gas is wasted to the atmosphere through a gas bleeder located at each end of the boiler house. Blast furnace gas used in the boilers is not precleaned and contains an appreciable amount of flue dust. A light bed of coal is used in each boiler to insure more complete combustion of the gases.

Flue dust from the dust collectors must be sintered prior to re-use in the blast furnaces. This process is similar to that described in the operation of the sinter plant at the zinc plant. Raw materials consist essentially of flue dust and scale with small amounts of cinder and coke dust. Heat for the operation is supplied by natural gas. Downdraft exhaust fans are located under the pallets and products of combustion are discharged to the atmosphere through two steel stacks approximately 80 feet high and 6 feet in diameter.

Molten pig iron from the furnaces flows into brick-lined ladles of 40-ton capacity and is transported to the open hearth mixer. The mixer is a large gas-heated vessel almost completely enclosed where the hot metal is stored until needed by the open hearth department.

Open Hearth

Steel is made in 13 open-hearth furnaces, each rated at 110 net ton capacity.

The open hearth is a shallow, saucer-shaped hearth completely enclosed with fire brick and heated on the ends by gas flames. A layer of scrap iron and limestone is charged into this shallow hearth and on this, the molten pig iron is poured. Charging time varies, but usually 3 to 4 hours are required. A charging machine is used to charge the necessary materials for a heat. Other materials are charged into the furnace during the heat, depending upon the type of steel to be made. Usually, each heat requires 10 to 12 hours.

Preheated air is mixed with the gas, forced into the furnace and made to burn over and around the layers of mix heaped on the hearth. Products of combustion and any material volatilized in the furnace are discharged to the atmosphere through a brick-lined, steel plate stack 6 feet in diameter and 150 feet high.

Slag and steel are tapped from separate ports at the lower side of the furnace and flow into separate ladles. The steel is then poured from the ladle into 5-ton ingot molds and transported to the stripper building.

Blooming and Billet Mills

The ingots remain in the molds about 3 hours, and are then removed by the stripper crane and placed in soaking pits where they are heated to a high temperature for rolling. The pits are brick-lined, steel-bound furnaces, heated by natural gas or fuel oil and located at one end of the rolling-mill building. Products of combustion are discharged into the atmosphere through six stacks, 5 feet in diameter and 100 feet high.

When the ingots are ready for rolling, they are withdrawn from the pits by a crane which transports them to the mill conveyor table. The ingot is next passed through the 36-inch blooming mill several times to reduce the ingot to a 7½-inch square bloom. The bloom is passed through the 24- and 18-inch billet mills to produce a billet 2 inches square and cut to 30-foot lengths or 4- by 4-inch billets as required.

Some of the blooms produced are deseamed (scarfed) by passing them through a Linde desurfacer. The equipment consists of a metal enclosure, table, numerous small oxy-acetylene scarfing torches, a water spray and an exhaust fan to remove products of combustion. The torches are so placed that about one-sixteenth inch of metal is removed from all four sides of the bloom simultaneously. Water sprays wet the oxidized iron and carry it with some metallic particles into a settling tank beneath the machine where it is subsequently worked for recovery of iron. Some oxidized iron with the products of combustion are exhausted to the atmosphere through a 4- by 5-foot duct.

Steam for operation of the blooming, billet and rod mills is generated in 12 stoker-fired, coal boilers. Each boiler has a stack 127 feet high and 4 feet 6 inches in diameter.

Rod Mills

Two types of rod mills are used, the continuous rod mill, and the Garrett or looping rod mill. In each case, billets are heated in gas-fired ovens prior to rolling.

Products of combustion from the two continuous rod mill furnaces are discharged to the atmosphere through two stacks 110 feet high and 4 feet in diameter. There are three furnaces in the looping rod mill each with stacks 100 feet high and 4 feet 3 inches in diameter.

Wire Mill

This department fabricates many types of wire products. Only those operations which discharge some contaminants to the atmosphere are described in detail.

Rods to be drawn into wire are freed of scale or other foreign material, by immersing the coils in tanks of hot dilute sulfuric acid followed by a water rinse. Lime is applied to prevent rusting and to act as a lubricant in wire drawing. The lime coating is dried on the rods by baking in natural gas-fired ovens vented to the atmosphere. Spent acid from the cleaning department is neutralized and made into iron sulfate in a separate building.

The wire drawing operation consists of cold drawing rods through dies of decreasing diameter, thus decreasing the diameter but increasing the length, tensile strength and hardness of the product. Grease, soap powder or other lubricants are used before each draft. When the desired cross-section is obtained, the wire is wound into coils.

Four principal heat treating processes (annealing, patenting, normalizing, and spheroidizing) are utilized to provide products to meet the metallurgical requirements of the trade. The bundles are placed in large gas or coal-fired pots, or are moved slowly on a conveyor through ovens.

Most of the wire used in wire products or sold to the trade is galvanized. In a continuous process, the wire, taken from bundles, is annealed by passing it through a gas-fired bath containing molten lead. The wires are then passed successively through a bath of hot dilute hydrochloric acid, a water rinse, an air drier and a gas-fired bath of molten zinc. Excess zinc is then removed and the zinc coating smoothed mechanically by charcoal and asbestos wipers. There are three lead annealing baths (exhausted through a single stack) and four zinc baths (exhausted through a single stack). The major contaminants discharged to the atmosphere are products of natural gas combustion, except for possible leakage of lead and zinc into the firing chambers due to cracked or broken tubs.

Nails, staples, and spikes are manufactured in the nail mill. Most of these are made on high speed nail machines in which the head of the nail is formed by a hammer blow; then a predetermined amount of wire is fed into the machine to establish the length of the nail. Pinch dies close on the nail, and the cutter dies cut the wire to form the point. Nails are cleaned in a revolving tumbler with sawdust to remove grease and are then packed in kegs. There are no fumes or gases of any consequence which contaminate the atmosphere from this mill.

Large quantities of nails are further processed after leaving the nail mill; most important of the processes is nail galvanizing. In this process nails are cleaned by immersion in a tank of dilute hydrochloric acid and are then placed into a revolving, gas-heated tumbler. Metallic zinc and ammonium chloride are added in varying amounts depending upon the size of nails to be galvanized. The temperature is maintained sufficiently high to melt the zinc and cause it to adhere to the nails. The two tumblers are exhausted to the atmosphere through a single duct. Approximately 400 tons of nails are galvanized per month. In another process, baskets of nails are dipped into an acid bath, rinsed with water and then placed into a molten zinc bath. Gaseous and particulate matter from this operation are vented to the atmosphere through louvers in the roof. This process is intermittent and observations indicated that the amount of contaminants was small.

Many types of wire products are fabricated. Barbed wire is made on 40 automatic machines; a large tonnage of bale wire is produced; straight cut wire is made for further processing in other plants; wire strands for highway guard rails and steel cable are produced; woven wire fence and shearing highway reinforcing fabric are also made.

Eleven stoker-fired boilers supply the steam requirements for the various operations in the wire mill. Products of combustion are discharged to the atmosphere through eleven stacks, each 150 feet high and 5 feet in diameter.

PLANT OPERATION DURING SURVEY

During the interval between the incident in October 1948 and the start of collection of samples in January 1949, certain changes were made in the zinc and steel plant operations. In order to obtain data on the contaminants produced under operational conditions similar to those which existed in October 1948, the plants returned to the same operational procedures and production rates which existed at that time. The return to the same operational procedures and production rates was accomplished gradually in the zinc plant beginning on March 24, reaching a peak on April 17. The period January to March 24, 1949, was designated the period of "curtailed production" and the period March 24 to April 17, 1949, the "transition period." The zinc plant continued at a peak rate from April 17 through April 21, 1949, and the steel plant shut off the blowers, which had been added, and returned to the use of coal during this period which was designated the "test period."

The major changes in plant operations in the period from October 1948 to January 1949, were as follows:

Zinc Plant

(1) Smaller charges were used in the zinc spelters.

(2) The use of zinc skimmings was curtailed to about half that previously used.

(3) As a result of (1) and (2), production was curtailed to about 80 percent of normal.

(4) Steam injectors and natural gas burners were installed in the waste heat boilers to afford more complete combustion of producer gas.

(5) Bypass valves were installed in the acid plant so that a portion of the sulfur dioxide gas from the first lead chamber could be fed into the Gay-Lussac towers to increase the absorption of oxides of nitrogen.

(6) Gas burners were installed to replace coal in the retort drying kilns.

Steel Plant

(1) Blowers were installed in those boilers not previously so equipped in order to provide excess air and improve combustion.

(2) Natural gas burners were installed to replace coal in the wire annealing furnace pots.

Order of Changes, 1949

The changes taking place during the "transition" and "test" periods were made in the following order:

(1) March 24—additional amounts of skimmings, salt, and a slightly decreased amount of sintered ore were charged in the spelters.

(2) April 1—additional amounts of skimmings, sintered ore, and salt were charged.

(3) April 3—a gradual build-up in the amount of ore roasted, which reached maximum production during the week of April 17.

(4) April 6—additional amounts of skimmings charged in spelters.

(5) April 10—additional amounts of skimmings, sintered ore, and salt charged in spelters.

(6) April 17—additional amounts of skimmings, sintered ore, and salt charged in spelters.

(7) April 17—zinc plant at 100 percent production (as near as was practicable to obtain) compared to October 1948.

(8) April 18—steel plant shut off those blowers which had been recently installed and used coal to heat wire annealing pots.

(9) April 22—zinc and steel plants reverted to the same operational procedures and production rates which were in effect prior to the start of the "transition period."

RESULTS OF ZINC PLANT SURVEY

Roasters

The Hegeler and Herreshoff roasters are essentially closed systems except during the time material is raked from one grate to a lower one or when the doors are open in the Hegeler and while grates are chiseled in the Herreshoff.

Visual observation of these two operations indicated that very little dust escaped from the Herreshoff roasters, but that some dust did escape from the Hegeler furnaces during the raking operation. Materials escaping into the general air consist essentially of sulfur dioxide and ore dust, with the possibility of some sulfur trioxide. There is also some sulfur, as this material is stored in and conveyed from an area adjacent to these two operations.

Samples were collected for sulfur dioxide, total sulfur, chloride, fluoride, and arsenic at both furnaces and in addition total particulate matter was collected with an electrostatic precipitator over the Hegeler furnaces.

Results of analyses are shown in table 38. No chloride or fluoride was detected and traces of arsenic were found in only four of the seven samples. Since these samples were collected in an impinger, no distinction was made between gaseous and particulate matter.

With the exception of one high result for sulfur dioxide (SO_2) and total sulfur, the observed values of sulfur dioxide and total sulfur appear quite low, particularly when it is realized that the samples were taken in an effort to obtain maximum atmospheric concentrations. Based on these results and other observations, the contribution of the roasters to the general atmospheric pollution of the valley is not considered significant.

Sinter Plant

As stated previously in the description of the sinter plant operation, two exhaust stacks from the Cottrell units discharge gases and particulate matter into the atmosphere. One stack collects material from three Cottrell units and the other from two units. Sampling was confined to a single Cottrell exhaust at a point just below the header connecting the two units to the exhaust stack.

The total air flow through the stacks is 27,000 cubic feet per minute for the one connecting three units, and 33,000 cubic feet per minute for the one connecting two units. Thus, there is a total air flow through both exhaust stacks of 60,000 cubic feet per minute at standard conditions or 86.4 million cubic feet per day of operation.

The sinter plant is usually shut down during the day shift on Tuesday and 2 or 3 hours Friday and Sunday mornings in order to clean dust from fans and for general maintenance. The results of estimated pounds of contaminants per day are based on 24 hours operation and would, therefore, be correspondingly decreased depending upon the actual hours of operation.

The first series of samples for sulfur dioxide, total sulfur, arsenic, chloride, fluoride and acidity were collected in fritted bubblers without prior removal of any particulate matter. It was found that some solid material entered the bubbler and plugged the pores, and this caused considerable difficulty in obtaining sufficient and accurate rates of air flow. In the second series of samples collected at a later date, a filter paper holder described previously was used to remove particulate matter ahead of the bubbler. Several samples were also collected with the electrostatic precipitator and impinger in series in order to differentiate between particulate and gaseous forms of the contaminants.

The results of these tests in the No. 5 Cottrell unit of the Sinter Plant are shown in table 39.

It will be noted that there is fair agreement between total sulfur (calculated as SO_2) and the actual SO_2 found, although the total sulfur is slightly higher. The results show that some sulfur compounds are also present as particulate matter since a small amount of sulfur was found in certain of the filter paper and precipitator samples.

The chloride present in the stack gases was essentially particulate matter as shown by the two sets of samples collected with the electrostatic precipitator and impinger in series, as well as by the negative results obtained in the impinger sample when a filter paper was used in front of it. The total chloride found ranged from 54.8 to 102.1 milligrams per cubic meter. The fluoride present was also essentially in the form of particulate matter and ranged from 0 to 1.27 milligrams per cubic meter.

Arsenic is apparently present in the gaseous and particulate forms, as shown by the positive values obtained for both when precipitator and impinger were used in series.

Results for total particulate matter, zinc, lead, and cadmium vary considerably and there does not appear to be any relationship among the zinc, lead and cadmium present in the stack gases. The highest total particulate matter (1,270 milligrams per cubic meter) was found during the cleaning period when the voltage to the unit was shut off and the tubes were rapped. It was visually observed that the Cottrell units were not completely effective in removing particulate matter from the gases and that their operation was erratic. This and other factors probably explain the variance in total particulate matter found, and for this reason arithmetical averages were used instead of weighted averages in estimating pounds of contaminants per day.

The results from table 39 were averaged arithmetically and the total atmospheric pollution load calculated. The total sulfur from the two filter papers was not included in the averages because the amount found was small and the result would have to be proportioned among 14 samples. As stated previously, these calculations are based on 24 hour operation and a total air flow of 86.4 million cubic feet. The estimated

TABLE 38.—*Results of analyses of samples collected at roasters (ore roasting)*

Date (1949)	Location	Description of operation	Instrument	Sampling time (minutes)	Sulfur dioxide	Total sulfur as SO_2	Total P. M.	Zinc	Lead	Cadmium	Chloride	Fluoride	Arsenic	Other determinations
					Milligrams of substance per cubic meter of air									
Feb. 2	#1 Hegeler-charging platform.	Raking	Vacuum flask	Grab										CO_2=0.05 percent. CO=0.0025 percent. O_2=20.88 percent.
	#1 Hegeler-hood-charging platform.	do	do	Grab										CO_2=0.03 percent. CO=0.0025 percent. O_2=20.92 percent.
Feb. 9	#1 Hegeler-charging platform.	Normal	Impinger	15	1. 0									
			do	15		3. 6					0	0	0. 0008	
			Electrostatic precipitator.	13			9. 2	4. 8	0. 11	0. 05				
		Raking	Impinger	15		39. 6					0	0	. 0135	
			do	20	3. 0									
			Electrostatic precipitator.	15			45. 7	19. 4	. 32	. 19				
Feb. 10	Herreshoff-top platform	Chiseling grates	Impinger	12	117. 0									
				12		238. 0								
		Normal	do	20	24. 4									
				20		38. 4								
Apr. 13	do	Chiseling grates	do	22	15. 7									
				22		64. 3					0	0	. 0040	
		Normal	do	18	4. 0									
				18		28. 9					0	0	. 0005	
				20	5. 5									
				20		27. 4					0	0	0	
Apr. 20	do	Cleaning flues	do	30	17. 6									
				30		28. 7					0	0	0	
				30	24. 1									
				30		29. 2					0	0	0	

NOTE.—Impinger samples for each different operation at the Herreshoff roasters were taken simultaneously. Those at the Hegeler were taken successively. Ppm: Parts of substance per million parts of air by volume. Total P. M.: Total particulate matter.

TABLE 39.—*Results of analyses of samples collected in the No. 5 Cottrell exhaust stack (sinter plant)*

Date (1949)	Instrument	Sampling time: Start	Sampling time: Minutes	Ppm: Sulfur dioxide	Ppm: Total sulfur as SO_2	Ppm: Acidity as SO_2	Mg/m³: Total P. M.	Mg/m³: Zinc	Mg/m³: Lead	Mg/m³: Cadmium	Mg/m³: Chloride	Mg/m³: Fluoride	Mg/m³: Arsenic	Other determinations
Feb. 4	Vacuum flask	11 a. m.	(Grab)											CO_2=1.12 per-cent. CO=0.12 per-cent. O_2=19.56 per-cent. CH_4=0.05 per-cent.
	Bubbler	1:30 p. m.	23.6		1,291.0									
Feb. 7	do	1:15 p. m.	25			933.0					65.3			
	Electrostatic precipitator	11:15 a. m.	5				487.0	62.2	26.0	32.8				
	do	11:25 a. m.	5				268.0	26.9	23.6	20.0				
	Bubbler	11:55 a. m.	5	726.0										
Feb. 9	do	11:45 a. m.	10	776.0										
Apr. 14	Electrostatic precipitator [1]	9:45 a. m.	15		37.8		1,270.0				96.2	0.50	0.14	
	Impinger [1]				634.0						5.9	.14	.04	
	Bubbler (1)	10:30 a. m.	5	204.0										
	Bubbler (2)	10:40 a. m.	5	806.0										
	Bubbler (3)	10:50 a. m.	10		1,455.0						0	0	.10	
	Bubbler (4)	11:10 a. m.	10			1,024.0								
	Bubbler (5)	11:20 a. m.	10	1,030.0										
	Electrostatic precipitator	2:15 p. m.	10		6.2		424.0				91.5	0	.08	
	Do	2:25 p. m.	10				304.0	26.3	71.6	19.4				
	Bubbler (6)	2:35 p. m.	15		1,458.0						0	0	.33	
	Bubbler (7)	2:50 p. m.	6	1,129.0										
	Bubbler (8)	3 p. m.	5			1,106.0								
	Filter paper [2]	10:30 a. m.	70		19.0						56.0	.14	.06	
Apr. 18	Electrostatic precipitator	12:01 p. m.	5				769.0	64.0	44.1	22.4				
	Bubbler (9)	12:15 p. m.	5			1,597.0								
	Bubbler (10)	12:20 p. m.	6	1,456.0										
	Bubbler (11)	12:30 p. m.	6	1,381.0										
	Electrostatic precipitator [1]	3 p. m.	10		4.0		170.0				49.5	.35	.03	
	Impinger [1]				1,114.0						5.3	.92	.02	
	Electrostatic precipitator	3:15 p. m.	5				603.0	45.7	70.7	15.3				
	Bubbler (12)	3:30 p. m.	5		1,275.0									
	Bubbler (13)	4 p. m.	6	1,002.0										
	Bubbler (14)	4:10 p. m.	6	1,680.0										
	Filter paper [3]	12:15 p. m.	35		13.5						89.5	.39	.004	

[1] Electrostatic precipitator and impinger in series.
[2] Filter paper used to filter stack gases for bubblers (1) through (8).
[3] Filter paper for bubblers (9) through (14).

Ppm: Parts of substance per million parts of air by volume.
Total P. M.: Total particulate matter.

total atmospheric pollution load from the sinter plant exhaust stacks is as follows:

Constituent:		*Pounds per day*
Total sulfur (equivalent to 17,000 lbs. SO_2)		8, 500
Total particulate matter		2, 900
Zinc	250	
Lead	250	
Cadmium	100	
Chloride	400	
Fluoride	3	
Arsenic	0. 4	
Arsenic (gaseous compounds)		0. 7
Carbon monoxide		8, 100
Carbon dioxide		*120, 000

*Calculated from a carbon dioxide gas analysis value of 1.12 percent by volume.

These results indicate that the sinter plant is a significant contributor to the atmospheric pollution load, and consideration should be given to measures to improve these conditions.

Zinc Spelters

One furnace was selected for sampling purposes and the cycle of operation was followed on several different dates. Furnace No. 4 was selected as representative of the furnaces. The sampling location selected was at the east end of the furnace and at a point just inside the hood over the furnace and about 20 feet below the roof louvers.

Results of analyses of the samples are shown in table 40. It is evident from these results that the concentration of sulfur dioxide emitted from the zinc spelters is very low, about the same order of magnitude as that found in the general atmosphere.

The percent of total sulfur found in the particulate matter is relatively low, but this small amount is significant because of the large volume of air involved. The total sulfur is apparently present both in the form of a gas and particulate matter, since sulfur was shown to be present in both the impinger and electrostatic precipitator samples when these were collected in series. It will be noted that the total sulfur varies during the cycle and on different days.

Of the 30 samples collected for fluoride only four showed positive results. The four positive results were all found in samples collected on one day.

The chloride found was in the form of particulate matter since chloride was absent in impinger samples when collected in series with the electrostatic precipitator. The results show a definite increase in the amount of chloride during the "test period" when the amount of zinc skimmings was increased. After the "test period," the chloride returned to approximately the same value as found in the beginning of the study. The amount of chloride discharged reached a peak when all sections of the furnace were charged and then slowly decreased as the cycle progressed.

The amount of arsenic found was extremely small and appeared at different dates to be in the gaseous state, and as gaseous and particulate matter.

Some interesting trends are evident from the total particulate matter results. Four samples collected on February 7 and 8 averaged [3] 56..5 mg./m.^{3}; 8 samples on April 15 averaged 183 mg./m.^{3}; 10 samples on April 19 averaged 145 mg./m.^{3} and 8 samples on April 25 averaged 96 mg./m.^{3} The first four samples were collected during the period in which production was curtailed, while those on April 15 were collected during the "transition period" and those on April 19 were collected during the "test period," including full production. Those samples on April 25 represent a return to the production level which existed in January and February, 1949. In other words, about twice as much particular matter was emitted during the "test period" as during the period of "curtailed production."

Average results for zinc before and after the "test period," compared with average results during the "test period," also show that about twice as much zinc was emitted. The average values for lead do not show the same trend, there being no increase in the amount emitted during the "test period." Cadmium showed a twofold increase during the "test period." Chloride was about three times as high, probably due to the increased charge of zinc skimmings used during the "transition" and "test period."

The amount of carbon monoxide inside the hood over the spelter was found to vary from less than 100, to 200 ppm. No increase was noted during the "test period."

All of the results shown in table 40 were averaged [4] to calculate the pounds of contaminants emitted from the zinc spelters. Measuring the airflow through the hoods was no simple task. It was necessary to climb inside the hood and, by means of a velometer, attempt to determine the airflow. Another method was used in which a vane anemometer was attached to the end of a 16-foot pole and a traverse of the hood made. Several readings were made on different days by the two methods mentioned, and the average airflow estimated. The hoods over the furnaces were merely rectangular enclosures approximately 112 feet long, 14 feet 10 inches wide and 16 feet high. The hood extended 2 feet 6 inches over the edge of each side of the furnace. The total airflow through the No. 4 furnace hood was found to vary from 225,000 to 480,000 cubic feet per minute. As pointed out previously, the airflow through these hoods will naturally vary depending upon the wind direction, velocity and outside temperature. The results of six measurements were averaged and the value of 400,000 cubic feet per minute for each hood was used in these calculations. Thus the estimated total airflow through the hoods of nine furnaces was 5,000 million cubic feet per 24 hours.

The estimated pounds per day of contaminants discharged into the atmosphere from the nine zinc spelters is as follows:

Constituent	Pounds per day	
	Test period	Curtailed production
Total particulate matter	42, 500	20, 800
Zinc	24, 400	12, 200
Lead	100	100
Cadmium	220	100
Sulfur	2, 300	900
Chloride	5, 000	1, 850
Fluoride	Trace	0
Arsenic	4	4
Sulfur dioxide	560	560
Carbon monoxide	54, 400	54, 400
Carbon dioxide	600, 000	* 600, 000

* Estimated from the results of three gas analyses, which averaged 0.13 percent by volume.

[3] Weighted averages were used in these calculations instead of arithmetic averages because of the difference in the range of values for the various cycles of operation. The following times were alloted: Charging 3 hours, normal operation 15 hours, and drawing metal 6 hours per day.

[4] See footnote 2, table 45, page 104.

TABLE 40.—*Results of analyses of samples collected inside of hood, east end of No. 4 spelter*

Date (1949)	Description of operation	Instrument	Sampling time		Ppm	Milligrams of substance per cubic meter of air								Other determinations
			Start	Minutes	Sulfur dioxide	Total sulfur	Total P. M.	Zinc	Lead	Cadmium	Chloride	Fluoride	Arsenic	
Feb. 7	Normal operation	Impinger (2)	1:40 p. m.	30	1.0	1.2					0.6	0	0.012	
		Elec. precipitator	do	15			29.5	9.2	0.07	0.22				
	Drawing metal	Impinger	3:15 p. m.	10		.7					2.8	0	.01	
		Elec. precipitator	do	15			56.1	27.5	.09	.25				
		Elec. precipitator	do	10			68.1	35.5	.19	.21				
Feb. 8	Charging furnaces	Impinger	9:15 a. m.	10		7.1					17.0	0	.022	CO=120 ppm. NBS CO detector.
		Elec. precipitator	do	10			72.2	15.7	.17	.26				
Apr. 15	Charging, pulling condensers	Impinger	do	10		3.9					26.5	0.07	.021	
		Elec. precipitator	do	10			283.0	96.0	.73	1.66				
	Near end of charging	Elec. precipitator	9:30 a. m.	15		3.3	111.0				33.5	0	0	CO_2=0.15 percent. CO=0.02 percent. O_2=20.85 percent.
		Impinger*	do	15		7.5					0	.07	.007	
	Charging completed ¾ sections fired.	Elec. precipitator	10:45 a. m.	20		1.9	221.0				31.6	0	0	
		Impinger*	do	20		2.5					0	.10	.023	
		Elec. precipitator	11:10 a. m.	5			207.0	124.0	.51	2.31				
	Normal operation	Impinger	1:15 p. m.	15	.3									
		Elec. precipitator	do	15			200.5	120.5	.39	.90				
	Do	Elec. precipitator	1:35 p. m.	15		2.6	135.0				18.6	0	0	CO_2=0.10 percent. CO=0.01 percent. O_2=20.79 percent.
		Impinger*	do	15		8.0					0	0	.007	
	Drawing metal first 4 sections	Elec. precipitator	3:00 p. m.	10		3.2	165.0				17.7	0	0	
		Impinger*	do	10		1.8					0	.11	.017	
	Do	Elec. precipitator	3:15 p. m.	10			140.5	83.0	.50	.50				
Apr. 19	Charging, drawing metal, scraping, and pulling retorts.	Elec. precipitator	7:30 a. m.	20		2.5	67.6				10.3	0	.007	
		Impinger*	do	20		2.5					0	0	.005	
		Elec. precipitator	7:50 a. m.	15			300.5	96.7	.65	3.13				
	Charging complete, replacing condensers one side.	Elec. precipitator	9:05 a. m.	15		4.7	255.0				55.5	0	.021	
		Impinger*	do	15		3.5					0	0	0	
		Elec. precipitator	9:20 a. m.	15			332.0	92.0	.24	1.34				
	Charging completed ¾ sections fired.	Elec. precipitator	10:20 a. m.	15		4.9	75.0				12.3	0	.007	
		Impinger*	do	15		1.2					0	0	.009	
		Impinger	10:35 a. m.	15	.6									
		Elec. precipitator	do	15			83.3	23.0	.14	.39				
	All sections fired	Elec. precipitator	1:40 p. m.	15		4.5	82.6				11.3	0	.002	CO=150 ppm. NBS CO detector.
		Impinger*	do	15		1.6					0	0	0	
	Do	Elec. precipitator	1:50 p. m.	15			122.5	67.0	.15	.42				
	Drawing metal first section both sides.	Elec. precipitator	3:00 p. m.	15		4.5	57.2				7.3	0	0	
		Impinger*	do	15		1.1					0	0	0	
		Elec. precipitator	3:15 p. m.	15			73.0	29.9	.27	.09				
Apr. 25	Charging almost completed 1 side fired.	Elec. precipitator	10:15 a. m.	15		3.5	97.0				11.8	0	.012	
		Impinger*	do	15		3.4					0	0	0	
		Elec. precipitator	10:35 a. m.	10			176.0	109.0	.93	.34				
	All sections fired	Elec. precipitator	11:15 a. m.	15		2.6	70.4				9.9	0	.012	
		Impinger*	do	15		1.1					0	0	.007	
		Elec. precipitator	11:40 a. m.	10			125.5	73.5	.95	.26				
		Elec. precipitator	1:30 p. m.	15		3.1	56.0				7.8	0	.009	
		Impinger*	do	15		1.0					0	0	0	
		Elec. precipitator	1:45 p. m.	15			102.5	48.0	.18	.70				
	Drawing metal first 4 sections both sides.	Elec. precipitator	3:00 p. m.	15		1.2	53.6				9.0	0	.012	
		Impinger*	do	15		1.2					0	0	.007	
		Elec. precipitator	3:18 p. m.	15			85.0	45.4	.33	.33				

NOTE.—The (*) beside instrument indicates that electrostatic precipitator and impinger samples were collected in series. Ppm: Parts of substance per million parts of air by volume. Total P. M.: Total particulate matter.

The values indicate that the major portion of the particulate matter discharged into the atmosphere from the spelters is zinc, essentially in the form of zinc oxide. The amount of chloride and sulfur compounds (as particulate matter) discharged is relatively small; and the remaining constituents of the particulate matter are not considered significant contributors to the atmospheric pollution load. The sulfur dioxide emitted from the spelters is not considered significant. Particulate matter, carbon monoxide and carbon dioxide are considered as major contributors to the general atmospheric pollution load.

The estimates indicate that consideration should be given to measures to reduce the amount of particulate matter and carbon monoxide from the zinc spelters.

No. 1 Waste Heat Boiler

Samples were collected in the stack of the No. 1 waste heat boiler at a point about three feet above ground level. In the first series of samples it was found impossible to obtain representative samples because of condensation in the sampling and electrostatic precipitator tubes due to the amount of steam introduced by the steam injector. Therefore, the results of this series are not included. During the "test period" a filter paper holder containing Whatman 42 paper was used in series with an impinger. The filter paper and impinger liquid were analyzed separately for total sulfur, chloride, fluoride, and arsenic. A separate impinger was used for collection of samples for determination of total particulate matter, including zinc, lead, and cadmium.

Additional samples were collected in the No. 1 waste heat boiler stack after the "test period" to determine the effect of the installation of steam injectors and burners on the amount of particulate matter from these boilers. However, during the time which elapsed between the samples collected during the "test period" and the second series of samples, the No. 1 zinc spelter furnace was rebuilt to incorporate changes to improve combustion of the producer gas. The results of the samples collected in the No. 1 stack are shown in table 41.

It will be observed that those samples collected during the "test period" while metal was drawn from the spelter show about five times as much total particulate matter as the samples collected after the "test period." It is interesting to note that the ratio of zinc to total particulate matter remained about the same during and after the "test period" as well as when drawing metal and during normal operation.

Total sulfur, essentially sulfur dioxide, remained fairly constant during normal operation and during the period when metal was withdrawn. This was to be expected since the sulfur in the stack gases was derived principally from the coal used in the gas producers.

The marked decrease in particulate matter and zinc after the furnace was rebuilt and the installation of steam injectors and burners is worthy of note, as a similar decrease might be obtained in other spelters.

The results from table 41 were used to estimate pounds of contaminants per day based on a total air flow through the nine waste heat boiler stacks of 600 million cubic feet per day. In the estimation of these values, except for sulfur and sulfur dioxide, it was assumed that drawing metal required 6 hours per day and the balance of the time was used for normal operation. The estimated results are divided into "test period" and "curtailed production" and are as follows:

Constituent	Pounds per day	
	Test period	Curtailed production
Total particulate matter	21, 600	8, 300
Total sulfur (from filter paper)	2, 800	
Zinc	5, 200	1, 500
Lead	50	20
Cadmium	2	. 5
Chloride	410	
Fluoride	15	
Arsenic	5	
Sulfur dioxide (from impinger samples)	34, 000	
Carbon monoxide	1, 170	

The estimates indicate that consideration should be given to measures to reduce the amount of particulate matter and sulfur dioxide discharged by the waste heat boilers.

Waelz Plant

Samples at the Waelz oxide plant were collected in the Cottrell stack just past the exhaust fan. The results of analyses including the approximate pounds of contaminants discharged per day are shown in table 42. These results show that the Waelz plant does not contribute materially to the general atmospheric pollution load.

Zinc Dross Plant

Particulate matter and gases from the 10 zinc dross retorts escape into the atmosphere through roof louvers where samples were collected. Results of analyses of these are as follows: total particulate matter was 40.5 mg/m^3; zinc, 18.5 mg/m^3; lead, 7.1 mg/m^3; cadmium, 0.005 mg/m^3; total sulfur, 0.9 mg/m^3; chloride, fluoride and arsenic, 10.4, 0.0, and 0.015 mg/m^3, respectively.

Since the airflow through the louvers was obviously small, the total contamination from this source was considered negligible.

Acid Plant

Samples were collected in three of the six Gay-Lussac stacks as each represents a different initial source of sulfur dioxide. Except for leaks these stacks are the only point of escape for contaminants. Results of analyses are shown in table 43.

These results indicate that total sulfur, acid gases and oxides of nitrogen are discharged into the atmosphere at an inconstant rate. Visual observation of the brownish yellow plume from the Gay-Lussac stacks during the course of this study was an additional indication of the erratic discharges from these stacks.

The results from table 43 were averaged and used to estimate pounds of contaminants per day, based on a total airflow of 43 million cubic feet per day through the six Gay-Lussac stacks. These amounts are as follows:

Constituent:	*Test period*	*Curtailed production*
Total sulfur as S (pounds)	2,500	1, 400
Oxides of nitrogen	8,500	6, 100

Table 41.—*Results of analyses of samples collected in No. 1 waste heat boiler*

Date (1949)	Description of operation	Instrument	Sampling time		Milligrams of substances per cubic meter of air							
			Start	Minutes	Total sulfur	Total P. M.	Zinc	Lead	Cad-mium	Chloride	Fluoride	Arsenic
Apr. 20	Drawing metal from furnace	Filter paper*	3 p. m.	10	67. 0					25. 7	0. 28	0
		Impinger	do	10	669. 0					0	0	0. 050
		Impinger	2:45 p. m.	10		2, 455. 0	529. 0	2. 45	0. 21			
Apr. 21	Normal operation	Filter paper*	2:13 p. m.	15	69. 5					10. 3	. 55	. 197
		Impinger	do	15	383. 0					0	0	. 004
		Impinger	2:35 p. m.	15		227. 0	43. 5	1. 02	. 03			
	Drawing metal from furnace	Filter paper*	3:30 p. m.	10	88. 5					17. 5	. 36	
		Impinger	do	10	324. 0					0	0	. 070
		Impinger	3:45 p. m.	10		1, 775. 0	555. 0	2. 38	. 02			
June 13	do	Impinger	2:15 p. m.	10		399. 0	84. 4	. 39	. 04			
		Filter paper*	2:30 p. m.	15								
		Impinger	do	15						0	0	
June 15	Normal operation	Impinger	12:01 p. m.	10		414. 0	72. 4	1. 34	. 08			
		Filter paper*	12:15 p. m.	10								
		Impinger	do	10						0	0	
		Filter paper*	12:30 p. m.	10								
		Impinger	do	10						0	0	
		Impinger	12:40 p. m.	10		29. 0	3. 4	0	. 02			

Note.—Total P. M.: Total particulate matter. *Filter paper and impinger were used in series.

TABLE 42.—*Results of analyses of samples collected in Cottrell exhaust-Waelz plant, Feb. 8, 1949*

Instrument	Sampling time (minutes)	Total sulfur as SO_2 ppm	Milligrams of substance per cubic meter of air							Other determinations
			Total P. M.	Zinc	Lead	Cadmium	Chloride	Fluoride	Arsenic	
Elec. pptr	9		9.3	2.5	0.10	0.001				
Do	7		15.3	4.7	.02	.024				
Impinger	15	385.0					11.3	0.7	0	
Vacuum flask	Grab									CO_2=4.38 percent. CO=0.67 percent. O_2=15.46 percent. H_2= .19 percent.
		Approximate pounds of contaminants discharged per day [1]								
		400.0	10.0	3.0	0.6	0.1	10.0	0.6	0	

[1]Based on an airflow of 13 million cubic feet per day.

NOTE.—Ppm: Parts of substance per million parts of air by volume, calculated as sulfur dioxide. Total P. M.: Total particulate matter.

This is the main source of discharge of oxides of nitrogen into the atmosphere, and this operation should be controlled by careful plant supervision.

Cadmium Plant

The processes of the cadmium plant are conducted in batch operation, with the exception of the cadmium retorts. Sampling points were located in each of the natural draft exhaust stacks just above the sulfating, purification and precipitation tanks. Stack samples were collected during the time of maximum discharge of contaminants to evaluate the atmospheric pollution load under the worst conditions. Results of the analyses of these samples are shown in table 44.

It will be noted that the first value for total sulfur is approximately 45 times greater than the second value. This wide variation is apparently due to the fact that the first sample was collected during the addition of sulfuric acid to the sulfating tank at which time the majority of the sulfur dioxide is liberated. The second sample was collected 1¾ hours later after the reaction had subsided. The high concentration would occur only for about 1 hour each day; however, the total sulfur liberated is not considered significant since the total volume of air through the stack was small. The amount of arsine discharged was considered negligible and tests for cyanide and hydrogen sulfide were negative.

No. 3 and 4 purification tanks usually contain residual

TABLE 43.—*Results of analyses of samples collected in Gay-Lussac stacks*

Date (1949)	Stack No.	Instrument	Sampling time (minutes)	Parts of substance per million parts of air by volume		
				Total sulfur as SO_2	Oxides of nitrogen	Total acidity as sulfuric acid
Jan. 31	5	Bubbler	20	197		
		Vac. bottle	Grab		420	
		Bubbler	3			588
	3	do	3	455		
		Vac. bottle	Grab		1, 225	
		Bubbler	5			1, 115
	1	do	15	615		
		Vac. bottle	Grab		455	
		Bubbler	5			763
Apr. 13	1	do	9			816
		do	6	1, 143		
		Vac. bottle	Grab		1, 300	
	3	Bubbler	2			1, 023
		do	10	214		
		Vac. bottle	Grab		2, 100	
Apr. 20	1	Bubbler	10	642		
		do	5			775
		Vac. bottle	Grab		1, 800	
	3	Bubbler	10	821		
		do	6			491
		Vac. bottle	Grab		960	
June 15	1	do	Grab		2, 870	
	3	do	Grab		2, 520	
	5	do	Grab		710	
June 16	1	do	Grab		1, 240	
	3	do	Grab		1, 180	
	5	do	Grab		630	

TABLE 44.—*Results of analyses of samples collected in cadmium plant*

Location and description of operation	Date (1949)	Instrument	Sampling time (minutes)	Ppm			Mg/m³	Other determinations
				Total sulfur as SO_2	Arsine	Stibine	Total particulate matter	
No. 1. Sulfating tank—during charging and addition of sulfuric acid.	Jan. 28	Bubbler	¾	13, 124				Halogens present.
	do	do	1		0. 003			Halogens, SO_2 present.
No. 1. Sulfating tank—1¾ hours after charging and addition of acid.	do	Impinger	2		. 054			H_2S, cyanides-negative.
	do	Bubbler	5	300				$CO=0.14\%$. $CO_2=1.10\%$. $O_2=19.58\%$.
No. 1. Sulfating tank—½ hour after charging and addition of acid.	Feb. 16	do	20			0		Cyanides-negative.
No. 3. Purification tank—during addition of acid	Jan. 25	do	20		3. 74			$CO=0$. $CO_2=0.4\%$. $H_2=0$. $O_2=20.84\%$.
No. 4. Purification tank—reprecipitation	do	do	5		. 48			Halogens-negative.
No. 4. Purification tank—5 minues after zinc dust was added.	Feb. 16	do	5			0		
No. 5. Precipitation tank—after addition of zinc dust	Jan. 25	do	30		. 23			Do.
No. 5. Precipitation tank—during addition of zinc dust	Jan. 27	do	8		1. 97			Halogens, H_2S-negative.
	do	do	8		4. 14			Spectrograph: Zn, Pb, Mg, traces of Cd, Fe, Si, Al, Cu, B.
	Feb. 15	do	1			. 196		
	Feb. 16	do	5			. 221		$H_2=2.37\%$. $CO_2=0.06\%$. $O_2=20.4\%$.
No. 5. Precipitation tank—10 minutes after addition of zinc dust.	do	do	5			0		
Cadmium retort exhaust—duct—normal operation (2) [1]	Jan. 23	Elec. precipitator	20				41. 7	Spectrograph: Cd, Pb, Sn, Ge, Zn, traces of Fe, Si, B, Mg, Cu, Tl.
Cadmium retort exhaust—duct—normal operation (3)	Jan. 27	do	15				95. 6	
	Jan. 28	do	15				56. 5	$CO=$trace. $CO_2=0.78\%$. $O_2=19.58\%$.
Cadmium retort exhaust—duct—charging (3)	Feb. 2	do	10				1, 120. 0	

[1] Numbers in ( ) refer to number of distillation retorts in operation Ppm: Parts of substance per million parts of air by volume. Mg/m³: Milligrams of substance per cubic meter of air.

Measurements of airflow in study of stack effluents.

zinc dust when the acid liquor is pumped into the tank. The amount of arsine was found to be highest just after the addition of acid and decreased rapidly after the reaction subsided. No stibine was found in these tanks. Tests for halogen and hydrogen were negative.

Conditions in the No. 5, or final, precipitation tank are similar to the purification tanks. Note that arsine and stibine are highest during the addition of zinc dust, but the amount decreased rapidly within 5 to 10 minutes resulting in a relatively low concentration for the entire operation. Hydrogen, arsine and stibine are generated due to the reaction of zinc dust and sulfuric acid.

Samples for particulate matter from the cadmium retorts were collected in the exhaust duct on the discharge side of the fan after the material had passed through a bag type collector. However, at the time the samples were taken the collector was not equipped with bag filters. Results of analyses of samples shown in the table indicate that the highest concentration of particulate matter was found during the charging operation. The four samples for total particulate matter were combined for a subsequent chemical analysis with the following results:

	Percent
Cadmium	77.0
Zinc	2.6
Chloride	1.5
Lead	.98
Sulfur	.43
Fluoride	.24
Arsenic	.05

The values shown in table 44 for total particulate matter and the results of analysis of this material were averaged using the charging period as one-half hour per day and normal operation as 23½ hours per day. This average value was used to estimate the pounds of contaminant per day based on an airflow of approximately 2½ million cubic feet. These results are shown below:

Constituent:	Pounds per day
Total particulate matter	13.0
Cadmium	10.0
Zinc	.3
Chloride	.2
Lead	.1
Sulfur	.05
Fluoride	.03
Arsenic	.007

Based on these results and other observations, it is believed that the contribution of the cadmium plant to the atmospheric pollution of the valley is not significant. Nevertheless, the bag type collector should be equipped with filters and properly maintained.

Summary

Table 45 summarizes the estimated pounds of major contaminants per day discharged into the atmosphere from the various departments of the zinc plant.

Table 45 shows that more total particulate matter and carbon monoxide are discharged from the zinc spelters than other sections of the plant. The amount of particulate matter and zinc discharged from the spelters into the atmosphere during the "test period" was approximately twice that during the period of "curtailed production." There was an approximate twofold increase in cadmium; a threefold increase in chloride and total sulfur; but no difference in lead and carbon monoxide during the "test period."

The waste heat boiler stacks discharged about half as much total particulate matter as the zinc spelters during both periods of operation and more sulfur dioxide than the other combined sections of the zinc plant. A relatively large amount of zinc was found in these stacks which was apparently due to leakage from imperfect retorts and from the points at which the retorts are sealed into the furnace.

The major contaminant from the sinter plant was sulfur dioxide; smaller amounts of carbon monoxide and particulate matter, including zinc, lead, cadmium, and chloride were found.

The acid plant is the only section of the plant which discharged appreciable amounts of nitrogen oxides.

It is believed that the contribution of the roasters, Waelz plant, zinc dross plant, and cadmium plant to the general atmospheric pollution of the valley is not significant.

Recommendations

Consideration should be given to measures to (1) reduce the gaseous contaminants, particularly sulfur dioxide, and particulate matter discharged from the sinter plant Cottrell stacks; (2) reduce the particulate matter and carbon monoxide from the zinc spelters; (3) reduce the particulate matter and sulfur dioxide discharged from the waste heat boiler stacks and (4) reduce the discharge of oxides of nitrogen and acid mist from Gay-Lussac stacks.

RESULTS OF STEEL PLANT SURVEY

With reference to the flow diagram on page 91, the sampling locations used in the study of the steel plant are indicated by circled figures and are as follows: (1) Blast furnace boiler house, stack No. 7; (2) blast furnace gas line; (3) casting area of blast furnace; (4) catwalk on top of stoves; (5) stove stack at level of catwalk; (6) sinter plant stack; (7) catwalk above open hearth furnaces; (8) open hearth furnace, stack No. 7; (9) soaking pit stack; (10) blooming mill boiler house, stack No. 3; (11) desurfacer exhaust duct; (12) nail galvanizer exhaust duct; (13) acid cleaning bath in wire galvanizing department.

The results of analyses of the samples collected, with the exception of steam generating boilers (presented on p. 109), are shown in table 46.

Blast Furnace and Sinter Plant

Approximately one-fourth of the gas produced in the blast furnaces is wasted either by leakage or through bleeder valves. Most of this is lost through two bleeder valves in the boiler house and blowoff valves on top of the blast furnace. Samples of the blast furnace gas for chemical analysis were collected in the gas line to the boiler house.

Table 46 shows that the blast furnace gas contains approximately 26 percent carbon monoxide, a relatively large amount of particulate matter and smaller amounts of chloride and fluoride.

The particulate matter consists essentially of flue dust which contains a large amount of iron oxide. Values for

TABLE 45.—*Estimated pounds per day of major contaminants discharged into the atmosphere from the zinc plant*

Department	Total particulate matter		Sulfur dioxide		Other sulfur compounds as S		Zinc		Lead		Cadmium		Chloride		Fluoride		Carbon monoxide		Oxides of nitrogen	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Cadmium plant [1]	13	13									10	10								
Acid plant					[3] 1, 400	[3] 2, 500													6, 100	8, 500
Sinter plant [1]	2, 900	2, 900	17, 000	17, 000			250	250	250	250	100	100	400	400	3	3	8, 100	8, 100		
Zinc spelters [2]	20, 800	42, 500	560	560	[4] 900	2, 300	12, 200	24, 400	100	100	100	220	1, 850	5, 000	0	Trace	54, 400	54, 400		
Waste heat boilers [2]	8, 300	21, 600	[5] 34, 000	34, 000	[4] [5] 2, 800	[4] 2, 800	1, 500	5, 200	20	50	. 5	2	[6] 410	410	[6] 15	15	[6] 1, 700	1, 700		
Total	32, 013	67, 013	51, 560	51, 560	5, 100	7, 600	13, 950	29, 850	370	400	210. 5	332	2, 660	5, 810	18	18	64, 200	64, 200	6, 100	8, 500

NOTE: A=pounds of contaminants discharged per day during "curtailed production" period. B=pounds of contaminants discharged per day during "test period."

[1] No changes made in these plants; values used in totals for both "curtailed production" and "test period."

[2] Results of analyses of samples collected on Apr. 13 and 15 were included in the "test period" because the plant had reached nearly 100 percent production at that time.

[3] Collected in NaOH, also contains SO_2.

[4] Collected in electrostatic precipitator or on filter paper.

[5] No samples were collected for sulfur during "curtailed production" period. However, since the sulfur and sulfur dioxide are derived from the coal used in gas producers, it was assumed that these values would be the same for both periods.

[6] No samples were collected during the period of "curtailed production" for chloride, fluoride and carbon monoxide. It was assumed that these values would be the same as in the "test period."

TABLE 46.—*Results of analyses of samples collected in steel plant*

Location and description of operation	Instrument	Sampling time (minutes)	Milligrams of substance per cubic meter of air: Total P. M.	Iron	Total sulfur	Chloride	Fluoride	Other determinations
BLAST FURNACE DEPARTMENT								
Waste gas	Impinger	10	1, 783. 9	854. 3		9. 8	4. 60	CO=25. 7%. O_2= 0. 2%. CO_2=14. 9%. H_2=4. 0%.
Casting area	do	15			5. 18	2. 3	0	Mn=1. 69 mg/m³. CO=40 to 100 ppm.
	Elec. precipitator	15	32. 0	14. 4				
Catwalk above	Impinger	20			2. 02	2. 5	0	Mn=2.12 mg/m³. CO=20 to 500 ppm. SO_2=0.
	Elec. precipitator	20	27. 6	11. 9				
Stove stack	Impinger	20			5. 01	3. 5	. 16	Mn=0.088 mg/m³. CO=0.18%. SO_2=0.3 ppm.
	Elec. precipitator	20	4. 3	. 7				
Sinter stock	Impinger	20			117. 0	4. 4	. 22	Ignition loss=24. 8 mg/m³. CO=0.24%. SO_2=8.08-ppm.
	Elec. precipitator	20	174. 0	77. 0				
CATWALK ABOVE NO. 6 AND NO. 7 OPEN HEARTHS								
No. 6 receiving final charge of scrap	do	20	5. 7	. 7				Ignition loss=1.74 mg/m³. Mn and Cr present.
Do	Impinger	30			. 32	0	. 05	
During melting	Elec. precipitator	44	4. 6	. 7				CO=0 to 50 ppm.
Do	Impinger	25		. 59	. 59	0	. 07	Ignition loss=1.48 mg/m³. Mn and Cr present.
Tapping slag	Elec. precipitator	30	6. 7	1. 1				Ignition loss=1.27 mg/m³. Mn and Cr present.
Do	Impinger	30			. 67	0	. 11	

OPEN HEARTH STACK NO. 7								
First "heat"								
30 min. after addition of hot metal	do	35			.30	0	.02	
Melting period	Vacuum flask	(Grab)						O_2=9.3%. CO_2=9.13%. CO=trace.
Liming period	Impinger	30			.14	0	.02	Spectrographic sample collected during this entire heat showed Pb, Zn, Fe, Sn, Mg, Al, Mn; traces of Ag, B, Si, Cd, Sb, As, P.
After addition of raw ore and lime	do	30			38.20	0	0	
During tapping and addition of dolomite	do	11			.19	0	0	
Second "heat"								
New charge of scrap metal	do	10			.25	0	0	
After addition of scrap	Elec. precipitator	10	124.0	33.6				
After addition of hot metal	do	10	139.0	70.0				
Melting period	do	10	100.0	37.0				
Near end of flushing period	do	10	70.0	16.8				
Liming period	do	10	74.5	19.8				
During and after addition fluorspar	do	10	54.5	3.4			1.59	
During and after tapping	do	10	46.5	1.8				
Third "heat"								
Liming period	do	8	70.7				1.10	
Liming period	do	10	66.5					Lead=1.76 mg/m³.
During and after addition fluorspar	do	5	174.2				17.65	
Immediately following above	do	10	93.4					Lead=6.16 mg/m³.
During addition of more fluorspar	do	10	89.3				4.24	
Immediately after addition more fluorspar	do	10	84.0					Lead=4.59 mg/m³.
Before and during tapping	do	10	40.6				1.40	
BLOOMING MILL								
Desurfacer								Total fume=67.3% Fe. NO_2=41.5 ppm. $Fe(CO)_5$[5]=88 ppm. Cyanide-negative.
WIRE MILL								
Nail galvanizing	Impinger*	16				0	0	
	Elec. precipitator	16	197.0			49.5		Zinc=45.3 mg/m³. Lead=0.3 mg/m³. Cadmium=0.15 mg/m³.

NOTE.—Total P. M.: total particulate matter.

*Impinger and electrostatic precipitator in series.

total particulate matter and iron were obtained by computation on the assumption that the particulate matter found in the boiler stacks was representative of the blast furnace gas. From the value thus obtained for particulate matter and production figures from the plant that an average of 32 million cubic feet of gas is wasted per day, it was estimated that the gas contained 1,800 milligrams of particulate matter per cubic meter.

Samples were collected inside the blast furnace building during the time pig iron was cast, and on the catwalks on top of the blast furnaces. These results indicate that the particulate matter consists essentially of iron and small amounts of sulfur, chloride, and manganese. Carbon monoxide in the vicinity of the casting area varied from 40 to 100 ppm, and varied from 20 to 500 ppm on the catwalk. The higher values for carbon monoxide found on the catwalk are probably due to the proximity of the blast furnace blowoff valves to the sampling location. The results of analyses of samples collected in these two areas were not used to estimate pounds of contaminants per day because these samples represent conditions which exist in open areas and not emanating from stacks.

Results of analyses of samples collected in the stove stack indicate only small amounts of total particulate matter, total sulfur and other contaminants, with the exception of carbon monoxide. Results of analyses of samples collected in the sinter plant stack indicate that the significant constituents were particulate matter, carbon monoxide, and sulfur dioxide.

The atmospheric pollution load was estimated from the results shown in table 46 and from the total air flows in the various stacks. These values are shown in table 47.

TABLE 47.—*Estimated pounds per day of contaminants discharged into the atmosphere from the steel plant, excluding boilers*

Location	Total air volume (millions of cubic feet per day)	Estimated pounds per day									
		Total P. M.	Iron	Zinc	Lead	Manganese	Carbon monoxide	Sulfur dioxide	Total sulfur	Chloride	Fluoride
Blast furnace:											
Blast furnace gas	[1] 32	3,600	1,800				635,000			19	0.7
Stove stack	250	70	10			1.4	34,000	10	80	57	2.0
Sinter plant stacks	140	1,550	700				27,000	190	1,050	40	2.0
Open hearth: Open hearth stacks	374,400	2,100	600		100.0		600		[2] 5	0	39.0
Wire mill: Nail galvanizing stack	[3] 8	100		24						24	
Total		7,420	3,110	24	100.0	1.4	696,600	200	1,135	140	43.7

NOTE.—Total P. M. Total particulate matter.
[1] Amount wasted and leakage per day.
[2] One sample 945 pounds per day not averaged.
[3] Operates only 16 hours per day.

It will be observed in table 47 that the waste blast furnace gas discharged into the atmosphere contributes more carbon monoxide and total particulate matter than other operations in the blast furnace department. The sinter plant discharges a relatively large amount of particulate matter (essentially iron oxide and sulfur compounds) and carbon monoxide. Apparently contaminants discharged from the stove stack do not materially contribute to the general pollution load of the valley, with the exception of carbon monoxide. The amount of fluoride discharged is small and is not considered significant.

Based on the values in table 47, consideration should be given to measures which would reduce the amount of carbon monoxide and particulate matter discharged into the atmosphere from the blast furnace department.

Open Hearth Department

Samples were collected on the catwalk about 40 feet above the open hearth furnaces. These samples represent the contaminants discharged into the atmosphere through the roof louvers of the open hearth building. The results of analyses of these samples, shown in table 46 were not calculated to pounds of contaminants per day because of the variable airflow through the roof louvers. It will be observed, that at this height, the amounts of total particulate matter and other materials found were small. No chloride was detected, and the amount of fluoride found is considered insignificant. The small amount of fluoride was probably from the addition of this material to molds in adjacent areas.

No. 7 open hearth stack was chosen for the collection of atmospheric samples and the sampling location was about 4 feet above the bridge crane platform. Samples were collected during three complete heats on different dates and the results of analyses are shown in table 46.

No chloride and only small amounts of fluoride were found. Fluoride values during the first two heats were much lower than during the third heat. Seven hundred pounds of fluorspar was added during the third heat and 300 and 500 pounds respectively were added during the first two heats. Fluoride was essentially in the form of particulate matter and it will be noted that the amount found in the stack was greatest during and just after the addition of fluorspar.

The amount of total sulfur found was negligible with the exception of one result of 38.20 milligrams per cubic meter. A possible explanation is that this one sample was collected during the addition of a small amount of sulfur to the charge. Such additions of sulfur were infrequent and therefore the result was not used in the computed daily pounds of contaminants.

The total particulate matter, including iron, lead, and other materials, is greatest during the charging operation and reaches a maximum during and immediately after the

addition of hot metal. The total particulate matter then decreases as the heat progresses reaching a minimum at tapping. It will also be observed from the table that the percentage of iron in the particulate matter decreases as the heat progresses, with a rapid decrease found just before tapping. Lead was determined on three of the samples for particulate matter in order to ascertain the quantity discharged into the atmosphere. The amount found was small and is considered insignificant.

It will be observed from the calculated estimates shown in table 47 that total particulate matter, consisting of approximately 30 percent iron (43 percent Fe_2O_3) with other materials such as lead, zinc, tin, aluminum, calcium, magnesium, and silicate, represented the major substance discharged into the atmosphere from the open hearth stacks. Consideration should be given to measures to reduce the amount of particulate matter discharged into the atmosphere from the open hearth stacks. The amount of carbon monoxide was small, and it is believed that it, as well as total sulfur, chloride, and fluoride, does not contribute materially to the general atmospheric pollution load.

Blooming Mill

Samples collected in the blooming mill boiler stacks are discussed under section, "Fules Used in Zinc and Steel Plants."

As mentioned in the description of the steel plant, approximately 30 percent of the blooms are desurfaced. This operation is an intermittent one and the atmospheric contaminants were estimated in terms of one minute of operation. The normal cycle of operation consists of burning for about 0.35 minute with the torches on for a total of 0.5 minute. From production figures for the middle of April 1948, it was estimated that the torches were used for 78 minutes per day. Samples collected in the exhaust stack of the deseamer showed the following: oxides of nitrogen=41.5 ppm or 0.234 pound per minute of operation or about 18 pounds per day. Iron carbonyl[5]=88 ppm or about 2 pounds per minute of operation or 156 pounds per day. Total particulate matter consisted of 67.3 percent iron or about 95 percent Fe_2O_3. No cyanide was detected. The pounds per minute are based on a total airflow of 43,900 cubic feet per minute in the deseamer exhaust duct.

Apparently this operation does not contribute significantly to the general atmospheric pollution load.

The majority of the soaking pits are heated by natural gas. Based upon results of stack analyses from other natural gas-fired equipment, which showed either no carbon monoxide or only traces of it, it was decided to collect only one sample in the soaking pit stacks. The results of analysis of this sample are as follows:

Constituent:	*Percent*
Oxygen	17.47
Carbon dioxide	2.08
Carbon monoxide: [trace (less than 0.0025)]	
Nitrogen	80.45

It is believed that the soaking pits do not materially contribute to the general atmospheric pollution.

Wire Mill

A sample of solid material scraped from the access door of the stack from the lead annealing bath showed the presence of lead. Since this bath is heated by natural gas, the only possible source of lead in this stack is from leaks in the bath itself. These leaks usually occur only just before the steel tub is to be replaced. This stack would therefore not normally be considered a source of lead contamination. It was reported that only one such leak had occurred in about 10 years of operation and that one, about 6 months prior to this study.

Breaks in the zinc baths do occur quite frequently; however, the metal is frozen by insertion of a water cooled tube which reduces the possibility of zinc fumes entering the stack. It is believed that the lead and zinc baths, in the wire galvanizing plant, do not constitute an atmospheric pollution problem, since leaks are in the nature of accidental occurrences and are corrected as soon as practicable.

Samples collected in the hood over the acid cleaning bath in the wire galvanizing department showed 28.5 ppm acid gases calculated in terms of hydrochloric acid. From the standpoint of atmospheric pollution, this amount is considered insignificant.

Nail Galvanizing

The two nail galvanizing mills are exhausted to the atmosphere through one stack. Atmospheric samples were collected on the discharge side of the fan in the exhaust stack. The nail galvanizing mills are in operation for 16 hours per day. At the time these samples were taken, only one of the mills was in operation, the other being closed for repairs.

The results of the analyses of these samples are shown at the end of table 46. It will be noted that the total particulate matter consists essentially of chloride and zinc and small amounts of lead and cadmium. These results were used to estimate pounds per day and appear at the end of table 47. Since the amount of lead and cadmium together amount to less than 0.25 pound per day, these totals do not appear in the table. It will be observed that the total particulate matter, including zinc and chloride, is small.

It is believed that the nail galvanizing mill does not contribute materially to the general atmospheric pollution problem.

Summary

The total amount of contaminants in pounds per day discharged into the atmosphere from the steel plant, excluding steam generating boilers, is shown in table 47.

[5] The sample for iron carbonyl was collected by drawing the stack gas through a Whatman No. 42 filter paper and into a 550 ml. displacement flask by means of an aspirator bulb. The filter paper was used to remove particulate iron from the stack gas. The material collected in the displacement flask was analyzed for iron by the method outlined under "Collection and Determination of Contaminants," and the results were calculated to parts per million of iron carbonyl, although this substance was not actually identified. If the filter paper did not completely remove particulate iron, it would be reported as iron carbonyl. However, since the amount of iron reported as iron carbonyl is relatively small, the error introduced by this method for collection of the sample can be neglected.

The major contaminants discharged from the steel mill are carbon monoxide and particulate matter. The major source of these contaminants is the blast furnace waste gas. The stove stack and sinter plant stack are the next important sources of carbon monoxide. The open hearth and sinter plant are the other significant sources of particulate matter.

The contaminants emitted from the blooming and wire mill are not considered important as regards the general atmospheric pollution problem.

Recommendations

Consideration should be given to measures to (1) reduce the amount of particulate matter and carbon monoxide from the waste blast furnace gas, (2) reduce the amount of carbon monoxide discharged from the stove and sinter stacks, and (3) reduce the amount of particulate matter discharged from the sinter plant and open hearth stacks.

FUELS USED IN ZINC AND STEEL PLANTS

The principal fuels used for heating and the production of steam in the steel plant are coal, blast furnace gas, and natural gas. A standby supply of butane is stored in tanks in the event of a natural gas supply failure. Fuel oil is used to supplement the natural gas during a severe winter. However, only a small quantity of fuel oil was used during the winter of 1948 and during the time this study was made. The open hearth department is the largest single consumer of natural gas with the soaking pits second. Consumption in these two departments is approximately 9,500,000 and 2,200,000 cubic feet per day, respectively. Coal is used in the zinc plant for the gas producers, and natural gas is used for the roasters and miscellaneous purposes.

Table 48 was prepared from data obtained from the steel plant for a three month period, namely, September, October, and November, 1948; and from the zinc plant for the year 1948. Daily averages were calculated from this information. Table 48 shows the types and amounts of fuel consumed by the various departments. The average composition of these fuels is as follows:

TABLE 48.—*Fuels used in steel and zinc plants, daily averages, 1948*

Department	Tons of coal per day	Natural gas (thousands of cubic feet per day)	Blast furnace gas [1] (thousands of cubic feet per day)	Fuel oil (gallons per day)
Steel plant:				
Blast furnace	48	235	109, 071	10. 7
Blooming mill	213	11, 765		
Wire mill	185	3, 370		
Donora Southern R. R.	57			
Zinc plant:				
Gas producers	290			
Miscellaneous uses		850		
Total	793	16, 220	109, 071	10. 7

[1] In addition to the amount used, 32,000 M cubic feet per day are wasted.

1. Coal—dry basis—percent by weight—plant analysis.

Ash	Volatile matter	Fixed C	Sulfur
9. 6	34. 1	56. 2	2. 95
9. 7	34. 3	56. 0	3. 82

2. Natural gas—percent by volume—average of plant analyses.

Methane	84. 0	Pentane	0. 29
Ethane	9. 0	Hexane	. 04
Propane	3. 61	Carbon dioxide	. 04
Butane	1. 17	Nitrogen	1. 85

3. Blast furnace gas—percent by volume—average of plant analyses.

Carbon dioxide	13. 4	Hydrogen	3. 2
Oxygen	. 1	Hydrocarbons	. 4
Carbon monoxide	26. 1	Nitrogen	56. 8

4. Blast furnace gas—grab sample—percent by volume.

Carbon dioxide	14. 9	Hydrogen	4. 0
Oxygen	. 2	Nitrogen	55. 2
Carbon monoxide	25. 7		

	mg/cu. ft.
Chloride	0. 28
Fluoride	0. 013

5. Fuel oil—plant analysis.

	Percent
Sulfur	0. 81

Results of analyses of samples collected in steam generating boiler stacks are shown in table 50. Pounds of cantaminants per day discharged into the atmosphere were estimated from the values shown in table 50 and the total volume of flue gases. These values are shown in table 49.

A review of these data on boilers shows that in the steel plant, the blast furnace boilers discharge the greatest quantity of particulate matter. This is because of the large amount of iron in the blast furnace gas which is not scrubbed prior to use in the boilers. Coal is added infrequently to the blast furnace boilers, just enough to maintain a shallow layer on the grates to insure complete combustion of the entering blast furnace gas. The relatively low range of

TABLE 49.—*Estimated pounds of contamination per day discharged into the atmosphere from steam generating equipment*

Location and description of operation	Volume of flue gas (millions of cubic feet per day)	Estimated pounds per day: Total particulate matter	Iron	Total sulfur as S	Chloride	Fluoride
Blast furnace boilers (16 stacks—blast furnace gas, coal and oil)	650	12, 200	5, 800	550	375	75
Blooming mill boilers (13 stacks—coal and coke)	480	1, 900		8, 200	0	4
Wire mill boilers (11 stacks—coal)	450	1, 900		7, 700	0	4
Zinc plant waste heat boilers [1] (9 stacks in operation—coal)	600	21, 600		19, 800	410	15
Total		37, 600	5, 800	36, 250	785	98

[1] Based on samples collected during "test period."

Table 50.—*Results of analyses of stack samples from steam generating equipment*

Item number and location	Percent by volume					Milligrams of substance per cubic meter of air					
	Carbon dioxide	Oxygen	Carbon monoxide	Nitrogen	Methane	Total sulfur	Total particulate matter	Iron	Manganese	Chloride	Fluoride
1. Blast furnace boiler No. 7	3.6	17.9	Trace	78.4	0	21.2	221	97	---	10.7	1.6
2. Blast furnace boiler No. 7	14.0	9.4	0.01	76.5	---	---	373	183	4.0	---	---
3. Blast furnace boiler No. 7	17.4	.6	1.30	---	---	5.4	---	---	---	8.1	2.1
4. Blooming mill boiler No. 3	5.7	14.2	.01	80.1	0	275	63	---	---	0	.2
5. Blooming mill boiler No. 10	7.0	12.0	0	---	---	---	---	---	---	---	.05
6. Blooming mill boiler No. 12	6.0	14.4	0	---	---	---	---	---	---	---	---
7. Wire mill boiler No. 16	4.6	15.8	0	---	---	---	---	---	---	---	---
8. Zinc plant waste heat boiler No. 1	4.6	15.6	Trace	79.7	0	736	2455	---	---	25.7	.3
9. Zinc plant waste heat boiler No. 1	---	---	---	---	---	412	1775	---	---	17.5	.4
10. Zinc plant waste heat boiler No. 1	---	---	---	---	---	452	277	---	---	10.3	.5

Notes

Item 3. Average of 18 determinations by plant fuel department, Aug. 30, 1946. Fuel oil and natural gas used to supplement blast furnace gas.
Items 5 and 6. Average values from plant data June 1945.
Item 7. Average of 15 determinations by plant June 1945.

Item 8. This boiler is heated by waste producer gas after passage through the zinc spelter. Broken retorts would cause some zinc, lead, cadmium and other substances to appear in this stack. For more detailed explanation and results on items 8, 9, and 10, see No. 1 Waste Heat Boiler, referred to in Results of Zinc Plant Survey.
A trace of CO means less than 0.0025 percent.

values for total sulfur compared to that from the blooming mill and wire boilers is an indication of the small amount of coal used in the blast furnace boilers.

Total particulate matter found in the blooming mill boiler stacks was approximately one-fifth as great as the blast furnace boilers. This was expected since coal or coke are the only fuels used and would not contain more than small amounts of iron. However, the average total sulfur values were approximately 20 times greater than those found in the blast furnace boilers. The sulfur found was principally in the form of sulfur dioxide. No chloride was detected; and small amounts only of fluoride were found in the blooming mill and wire mill boilers.

Waste heat boilers at the zinc plant discharge about twice the amount of particulate matter as the blast furnace boilers, and more sulfur than the blooming mill and wire mill boilers combined. It was shown previously (No. 1 Waste Heat Boiler) that the particulate matter discharged consisted essentially of zinc and soot with smaller amounts of lead, cadmium, and sulfur compounds.

The particulate matter discharged into the atmosphere per day from steam generating boilers amounts to approximately 38,000 pounds; sulfur dioxide amounts to approximately 70,000 pounds; fluoride is considered negligible, with the exception of the amount discharged from the blast furnace boilers.

Consideration should be given to measures which would reduce the amount of particulate matter discharged from the waste heat and blast furnace boilers, and the sulfur dioxide from the waste heat, blooming mill, and wire mill boilers.

Atmospheric Pollution from Domestic Sources, Steamboats, Trains, and Automobiles

Robert B. Crothers

DOMESTIC SOURCES

To evaluate the role of domestic smoke in relation to atmospheric pollution in the Donora area, a study was made of the heating equipment of the homes and business buildings.

Furnaces

In the Donora area there are approximately 2,300 buildings, exclusive of heavy industry. Most of the buildings are relatively small and are heated by simple types of furnaces. The typical domestic heating plant is a hand-fired cast iron boiler supplying a hot-water or steam-radiator system. All of the boilers examined had overfired grates. Very little use was made of arches, bridge walls, or other devices to increase the efficiency of combustion. With the exception of some of the apartment dwellings and stores, all of the boilers had less than four square feet of grate surface.

Fuels

Mine-run coal is used extensively for heating in Donora, and gas and electricity for cooking. Some of the newer homes have gas- or oil-fired heating systems. Sixty percent

of the coal burned in domestic heating plants comes from one large mine near Monessen, and the remainder from a number of small privately owned mines. All of this coal comes from the Pittsburgh bed. From information obtained from mine operators and coal distributors, it was estimated that the Donora area burns approximately 52,000 tons of coal during the heating period. The average period during which heating fires are necessary for this area is 245 days, and the average temperature during this period is 43.6° F. (*1*). The average coal consumption through the heating period is, therefore, 210 tons per day.

The following is a range of values obtained from the analysis of coal from the Pittsburgh bed (*2*).

Constituent:	*Range in percent*
Volatile matter	31.2–40.7
Fixed carbon	53.2–63.8
Total carbon	75.8–86.1
Ash	6.6– 8.4
Hydrogen	5.0– 5.6
Nitrogen	1.4– 1.6
Oxygen	6.0– 8.2
Sulfur	1.3– 1.8

Estimation of Air Pollution

The following discussion and estimation of atmospheric pollution from domestic sources are based primarily on information and data obtained from the literature. Samples were collected from chimneys of business buildings and homes to verify and supplement the information obtained from the literature.

Combustion products from domestic heating units vary with operating conditions and type of fuel used. However, to obtain an estimate of the amount of contaminants from domestic heating sources the following calculations were made. The number of cubic feet of dry flue gas was calculated from the reported ratio of pounds of bituminous coal to cubic feet of flue gas with perfect combustion plus excess air based on the 12 percent carbon dioxide obtained by analysis of the flue gas (*1*). The value obtained, based on a fuel consumption of 210 tons per day, is 95,000,000 cubic feet. The amounts of carbon dioxide and carbon monoxide in pounds per day were calculated using 12 percent carbon dioxide and one percent carbon monoxide, found by analysis, and the calculated volume of flue gas. The amounts of chloride and fluoride were calculated in a similar manner using 2.6 and 5.2 milligrams per cubic meter, respectively. These values were obtained by analyses of the flue gas. The dry residue was calculated on the assumption that 3.0 percent of the coal used was discharged as particulate matter in the flue gas (*3*). The value for sulfur dioxide was calculated on the assumption that the volatile sulfur in the coal was 1.5 percent.

From the above data it was calculated that about 12,600 pounds of particulate matter, 12,600 pounds of sulfur dioxide, 1,400,000 pounds of carbon dioxide, and 74,000 pounds of carbon monoxide are discharged daily into the atmosphere.

It is emphasized that these values are only estimates but do serve the purpose of giving the relative magnitude of these contaminants from domestic sources.

Comment

To decrease atmospheric pollution from this source consideration should be given to smoke prevention measures. For example: (1) Local building ordinances might include provisions which would assure less smoke from the heating units of all the new buildings, and (2) owners of buildings from which there is frequent dense smoke should be given the benefit of an educational program on proper firing methods.

STEAMBOATS

The Monongahela River is one of the world's most important waterways in terms of tonnage of freight transported on it. Consequently, boats were considered as contributors to the atmospheric pollution and a study was made of fuel consumption of boats during passage through the Donora area.

Type of Motive Power

Two-thirds of the boats are coal-burning steamboats, and one-third are Diesel powered. There are also a few small gasoline-powered boats. The Diesels are relatively new and specifically designed for operation on this part of the Monongahela River. Most of the steamboats are more than 20 years old. Their original designs have been modified and horsepower increased since construction. These boats burn the better grade of local coal, but even so discharge considerable smoke.

River Traffic

The steamboats of the upper Monongahela River are especially adapted to the group of locks found there and the depth of channel. The boats are not so large nor the tows so long as those on the Ohio or the Mississippi River. The typical towboat which passes through the Donora area is steam driven with a stern paddle wheel which usually pushes three pairs of steel barges ahead of the boat. This formation is frequently modified when making a landing or preparing to enter the locks. At such times, one or more of the barges may be pulled along the side of the rest of the tow or even alongside the boat. It is during these difficult maneuvers that the greatest amount of visible smoke is produced.

The United States Army Engineers maintain the navigable channel of the river by dredging and operating a series of locks. The river between each pair of locks is actually a pond of slowly moving water. The minimum depth of the channel at any given point is fixed by the height of the dam at the next lock downstream. The Donora water level is set by the dam at Elizabeth, Pa. The next upstream rise in the river level is at Charleroi. The smoke from the boats using the pond between Elizabeth and Charleroi contributes to the general atmospheric pollution of the Donora area.

The data shown in table 51 were obtained through the courtesy of the United States Army Engineers. During the month of October (1948), 969 boats passed Donora. This exceeds the yearly average of 929 boats per month. During the period of the Donora incident (October 27–30), there was an average of 22 boats per day as compared to an average of 32 boats per day for the rest of October. This decrease

probably was due to the smog, since conversations with steamboat men revealed that all but the radar-equipped boats had great difficulty in navigating the Donora-Webster bend in the river during that period.

TABLE 51.—*River traffic in the Donora area for the year 1948*

Date (1948)	Number of boats				Tonnage	
	Steam		Diesel			
	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
January	335	330	141	139	31, 835	2, 066, 360
February	326	333	72	74	16, 250	1, 518, 010
March	228	230	133	136	50, 450	1, 440, 880
April	167	160	104	101	43, 209	975, 650
May	431	445	199	197	58, 350	2, 977, 590
June	390	389	160	159	63, 750	2, 523, 650
July	226	221	117	114	785, 550	1, 359, 500
August	393	396	174	172	74, 450	2, 609, 930
September	371	373	149	145	57, 400	2, 446, 730
October	334	334	148	153	67, 660	2, 238, 470
October 1	14	14	6	8	4, 150	101, 420
October 2	14	12	8	4	1, 760	71, 680
October 3	12	13	3	7	1, 000	90, 960
October 4	8	10	4	2	3, 250	63, 310
October 5	15	10	7	4	3, 200	64, 240
October 6	13	16	3	7	106, 100	107, 100
October 7	10	9	6	5	3, 150	57, 760
October 8	14	15	5	4	600	97, 870
October 9	17	16	6	5	5, 500	92, 020
October 10	10	16	5	7	3, 300	98, 320
October 11	12	10	2	4	67, 620	67, 620
October 12	12	10	6	4	4, 600	72, 880
October 13	12	12	3	2	1, 050	69, 410
October 14	10	10	6	4	71, 580	72, 880
October 15	8	11	1	6	----------	77, 950
October 16	11	7	5	3	6, 000	40, 500
October 17	11	17	8	6	2, 050	112, 270
October 18	12	13	4	7	1, 450	94, 100
October 19	12	8	5	4	2, 400	46, 400
October 20	13	14	4	5	4, 350	102, 580
October 21	6	7	4	2	1, 800	39, 320
October 22	13	9	6	7	4, 100	68, 400
October 23	8	13	5	4	1, 400	80, 500
October 24	11	8	5	5	1, 300	55, 400
October 25	7	9	6	11	600	73, 260
October 26	11	7	6	2	3, 150	45, 960
October 27	7	7	1	5	----------	48, 840
October 28	7	9	5	1	1, 500	52, 120
October 29	8	7	3	5	1, 100	55, 060
October 30	7	5	6	6	1, 600	54, 320
October 31	9	10	4	7	1, 000	66, 320
November	343	343	157	155	72, 300	2, 294, 500
December	339	340	133	138	56, 775	2, 279, 550
Total for year	3, 883	3, 893	1, 687	1, 683	1, 377, 979	24, 730, 820

Estimation of Air Pollution

Arrangements were made through the courtesy of one of the steel corporations to take samples aboard one of the boats of their fleet. A boat typical of the fleet of steamboats which regularly passes by Donora was chosen. This 427-ton towboat had two tandem compound steam engines developing a total of 800 hoursepower. Steam for the engines was supplied by four horizontal-return flue boilers. The boilers had automatic stokers and the coal was spread by steam jets. All products of combustion were discharged through two stacks just forward of the pilot house. At least one full-time engineer and one fireman were on duty at all times. During periods of more than average steam demand, forced draft blowers were used to aid in combustion of the coal.

During passage under about half of the bridges, the smokestacks were lowered by means of a hinged joint in the stack 8 feet above the level of the second deck. This lowering of the stacks momentarily interfered with the firing of the boilers. In the operation of the boat when it was approaching the locks or passing on short bends in the river, frequent use was made of slow speed or reverse. This change of speed caused a fluctuation of the steam pressure and required special attention for proper firing of the boilers. To meet the needs of these various conditions, a program of good firing practices had been established.

Information supplied by company officials indicated that, on the average, the boats going by Donora would burn 11 tons of coal or 1 ton of Diesel oil per day while navigating 4 miles of river adjacent to Donora. Since the steamboats contributed the major part of the pollution, calculations were made only for this type of boat.

To obtain an estimate of the amount of contaminants from the steamboats, the following calculations were made. The number of cubic feet of dry flue gas was calculated from the reported ratio of pounds of bituminous coal to cubic feet of flue gas with perfect combustion plus excess air based on the 6.3 percent carbon dioxide obtained by analysis of the flue gas (*1*).

The value obtained, based on a coal consumption of 11 tons per day, is 9,500,000 cubic feet. The amounts of carbon dioxide and carbon monoxide in pounds per day were calculated from analyses showing 6.3 percent carbon dioxide and 0.05 percent carbon monoxide in the stack exhaust gas. The amounts of chloride and fluoride were calculated similarly using 2.5 and 1.3 milligrams per cubic meter, respectively. These values were obtained by analyses of the stack exhaust gas. The particulate matter was calculated on the assumption that 3 percent of the coal used was discharged as particulate matter in the stack exhaust gas.

The value for sulfur dioxide was calculated in the manner described in the previous section on domestic sources of pollution.

From the above data, it was calculated that about 660 pounds of particulate matter, 660 pounds of sulfur dioxide, 74,000 pounds of carbon dioxide and 3,700 pounds of carbon monoxide are discharged daily into the atmosphere from the steamboats.

Comment

To decrease atmospheric pollution from this source continued attention should be paid to improving equipment and emphasizing good firing practices.

TRAINS

Eighteen freight and 6 passenger coal burning steam engines pass through the Donora area daily. A local railroad has 10 switch engines working continuously within the Donora area. These local trains operate within company property and also haul slag to a commercial slag paving company and to a slag pile north of Donora.

Two Diesel switch engines that were used part-time in this valley were not included in the calculation of the air pollution from trains, since it was felt that their contribution would not significantly affect the values obtained.

The railroad engines used in this area varied from small switch engines on the local railway to the large I type road engines on the passenger trains. The grade along the bend in the Monongahela River varies from 0.0 to 0.3 percent and the maximum curve is 3 degrees and 44 minutes. The morning and evening passenger trains stop at Donora and Webster. The freight trains operate at a reduced speed because of the limiting block signals. It was estimated by the railroad officials that on the average the locomotives use 75 percent of their maximum horsepower while in the Donora area. Most of the engines are stoker-fired, but a few are hand-fired.

It was estimated from information supplied by the railroad companies that through trains burned 3.5 tons of coal and the local trains 51 tons of coal per day while operating in the Donora area. To obtain an estimate of the amount of contaminants from trains, the following calculations were made. The number of cubic feet of dry flue gas was calculated from the reported ratio of pounds of bituminous coal to cubic feet of flue gas with perfect combustion plus excess air based on an estimated 14 percent carbon dioxide. The values obtained based on the above data were 1,300,000 cubic feet for the through trains, and 20,000,000 cubic feet for the local trains. The amounts of carbon dioxide and carbon monoxide in pounds per day were calculated from estimates of 14 percent carbon dioxide and 0.3 percent carbon monoxide from typical stack gas analyses supplied by the railroad companies.

The amounts of chloride and fluoride were calculated in a similar manner using estimated values of 2.5 and 1.3 milligrams per cubic meter (values obtained from boats), respectively.

The values for particulate matter and sulfur dioxide were calculated in the same manner as in the previous section on boats.

From the above data, it was calculated that about 200 pounds of particulate matter, 200 pounds of sulfur dioxide, 22,000 pounds of carbon dioxide, and 300 pounds of carbon monoxide are discharged daily into the atmosphere by the through trains; and that 3,000 pounds of particulate matter, 3,000 pounds of sulfur dioxide, 350,000 pounds of carbon dioxide, and 4,700 pounds of carbon monoxide are discharged by the local trains.

Comment

To decrease atmospheric pollution from trains consideration should be given to improvements in combustion equipment. A training program in good firing practices should be instituted for operating crews. There is a smoke-abatement program underway at the present time for through trains which should give increasingly better results as soon as the engineers and firemen get better equipment and become more proficient in the newer firing method.

AUTOMOBILES, INCLUDING TRUCKS

It was estimated that there were 3,000 automobiles in the Donora area. On the assumption that each vehicle burns 2 gallons or 12 pounds of gasoline per day, it is estimated that 36,000 pounds of fuel are consumed daily.

With the assumption that the exhaust gas contains 7 percent carbon monoxide and 9.8 percent carbon dioxide, and that there are 160 cubic feet of exhaust gas for each pound of fuel, then approximately 70,000 pounds of carbon dioxide and 30,000 pounds of carbon monoxide would be produced.

SUMMARY

Table 52 presents a summary of atmospheric pollution from domestic sources, steamboats, trains, and automobiles in terms of pounds of contaminants per day. It is again emphasized that these values are estimates and give only the relative order of magnitude of these contaminants. The data indicate that the major sources of particulate matter, sulfur dioxide and carbon dioxide are domestic sources and local trains; the major sources of carbon monoxide are domestic sources and automobiles.

TABLE 52.—*Summary of atmospheric pollution from domestic sources, steamboats, trains and automobiles*

Source	Pounds per day					
	Particulate matter	Sulfur dioxide	Carbon dioxide	Carbon monoxide	Chloride	Fluoride
Domestic	12, 600	12, 600	1, 400, 000	74, 000	15	30
Steamboats	660	660	74, 000	370	1. 5	. 8
Trains:						
Through	200	200	22, 000	300	. 2	. 1
Local	3, 000	3, 000	350, 000	4, 700	3. 0	1. 5
Automobiles	------	------	70, 000	30, 000	------	------

References

(*1*) Strock, Clifford: Heating and Ventilating's Engineering Databook. Industrial Press, New York (1948). Sections 2, 5, pp. 13, 53.

(*2*) Fieldner, A. C., et al.: Carbonizing Properties and Petrographic Composition of Pittsburgh-Bed Coal. Bureau of Mines Technical Paper No. 294 (1939).

(*3*) Department of Scientific and Industrial Research, Building Research Board: Heating and Ventilation of Dwellings. Post-War Building Studies, No. 19. H. M. S. O., London (1945). (Referred to by Marsh, Arnold: Smoke. Faber and Faber, London (1947). P. 38.

General Atmospheric Pollution

Harold J. Paulus and Herbert H. Jones

A thorough knowledge of the sources of pollutants is essential in a study of atmospheric pollution. Therefore, a study of the sources of air pollutants in the immediate Donora vicinity was made, which included the industries, boats, railroads, and domestic sources. Consideration also must be given to sources of pollutants other than those in the immediate vicinity, as a source of contamination many miles away could pollute another area due to wind currents. In the preliminary phases of this study, information was obtained on raw materials, production methods and finished products from the various industries in the Monongahela Valley, extending from Clairton to Charleroi. This information was important in considering pollutants that might come from outside the immediate area. Such sources of atmospheric pollution that cannot be overlooked are slag heaps, mines, and gob piles, which practically surround the Donora area.

SELECTION OF AIR SAMPLING STATIONS

To obtain information on atmospheric contamination throughout the Donora area, careful consideration was given to the selection of air sampling stations. Factors considered were major sources of contamination, altitude, density of population, location with reference to contaminants coming from outside sources and relationship of air sampling stations to the temporary United States Weather Bureau stations established for the study. Twelve air sampling stations were selected since this seemed an optimum number from the standpoint of the factors to be considered, and the personnel and equipment available. Of these, five were located across the valley on a line through the zinc plant, each one being associated with a major weather bureau station. The locations of the air sampling stations are shown in the map of the Donora area, figure 60. A description of these 12 air sampling stations follows.

Station No. 1

This station was situated on a graveled street on top of the highest hill in the area at an elevation of 1150 feet. It was on the northwest outskirts of the Donora Borough limits with only scattered houses in the near vicinity. Toward the north and northwest from the station, the steep hillsides were mainly open fields. Weather bureau station No. 6 was located about 200 yards east and 30 yards north. The active slag heap of the steel and zinc plants was about 0.5 mile away to the northwest. The steel plant in Monessen was in a southwesterly direction.

Station No. 2

This station was on a moderately traveled cindered street at approximately stack top height at an elevation of 910 feet in the northern part of Donora. The ground sloped steeply upward to the west and downward to the east with a valley running southeast toward the river. About 100 yards north of the station the street ran up to the top of a hill with an elevation 20 feet higher than the sampling station. Four two-story houses were situated in a row along the street west of the station, and several houses were located at higher elevations north and northwest and at lower elevations southeast of the station. The zinc plant was approximately 400 yards east. Weather bureau station No. 5 was located about 300 yards south and at a slightly higher elevation.

Station No. 3

This station, at an elevation of 780 feet, was located in an open lot about 70 yards directly west of the southern end of the zinc furnace building. A heavily traveled brick paved street formed the western boundary of the lot. The west side of this street was solid with homes and business establishments. The main portion of Donora was situated to the south and southwest of the station, and the steel plant was to the south. The zinc furnaces and acid plant of the zinc plant were north and northeast of the station. Railroad tracks ran along the zinc plant about 50 yards east of the station. Weather bureau station No. 4 was located about 25 yards northeast of the station.

Station No. 4

This station was on the east side of the river in the residential part of Webster at an elevation of 765 feet. It was on a hard-surfaced street intersection about three blocks north of the Donora-Webster bridge and one block west of Highway 88 (truck) which carries moderately heavy traffic. The south end of the zinc furnace building was directly west from the station and the rest of the zinc plant was northwest. The steel plant was south-southwest of this station. Railroad tracks with moderate traffic were located between the sampling station and the river which was 50 yards away. Weather bureau station No. 3 was located 2 blocks north.

Station No. 5

This station was in a residential section of Webster on the east slope of the valley at an elevation of 900 feet. The ground sloped sharply upward to the east and downward to the west toward the river. The hard-surfaced street on which the station was located was the highest north-south street in Webster. The houses were sparsely scattered along both sides of the street and on the slope down to the river bank level. The zinc plant was located west-northwest of the station at a distance of about 600 yards with the zinc furnaces directly west. The steel plant and the center of the Borough of Donora were southwest of this station. Weather bureau station No. 2 was located about 400 yards north.

Station No. 6

This station was on a paved road approximately 0.4 mile up Webster Hollow (contains part of Webster) from Highway 88 and at an elevation of 800 feet. A small creek ran

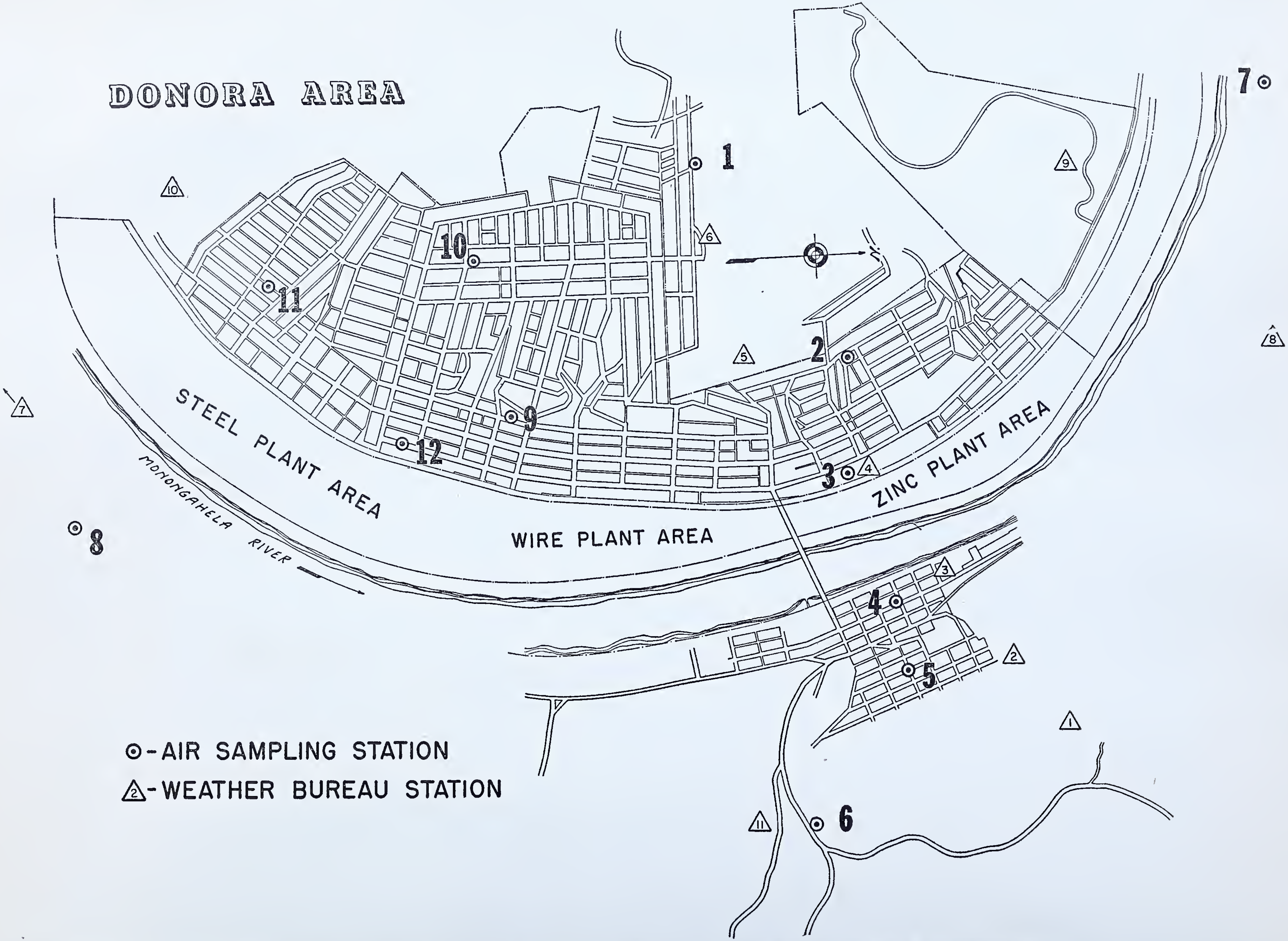


Figure 60.—*Map of Donora area showing location of air-sampling stations, and weather bureau stations.*

alongside the road toward the river. The valley was very narrow and the slope of the ground on either side was quite steep. Several houses were scattered along the south side of the road and on the south slope of the valley. The steel plant was southwest of the station and the zinc plant was west-northwest.

Station No. 7

This station, at an elevation of 750 feet, was in a graveled area near the junction of Highways 31 and 88, about 1.4 miles northwest of Webster. Railroad tracks paralleled the river which was about 100 yards south of the station. A slag company and the slag heap from the steel plant were across the river in a southwesterly direction at a distance of approximately 0.5 mile. The area behind the sampling station and the area across the valley were steep hills. A large gob pile from an active coal mine was in close proximity. The industrial plants and Borough of Donora were southeast of the station.

Station No. 8

This station, at an elevation of 1,000 feet, was located on the edge of a cliff on the east side of the river. It was directly east of the blast furnace department of the steel plant. Three houses were located in the general vicinity of the station. The city of Monessen and its steel plants were approximately 2 miles away in a west-southwest direction. The blast furnaces of the Donora steel plant were about 600 yards west and the open hearth building was about 1,000 yards north of the station. Weather bureau station No. 1 was located on the cliff about 0.25 mile south-southwest of the station.

Station No. 9

This station, at an elevation of 860 feet, was located at the Municipal building of the Borough of Donora. It was on the edge of the main business district and was surrounded by a mixture of business establishments and residences. The ground sloped sharply upward toward the west and gradually downward to the river toward the east. The open hearth department of the steel plant was southeast at a distance of 300 yards and the blast furnace was south of the station.

Station No. 10

This station, at an elevation of 970 feet, was located in a residential section of Donora near the western edge of the borough limits. It was near an intersection of moderately traveled paved streets. Two blocks west of the station was the border line between the residential section and open country. The steel plant at Monessen was located about 2 miles to the southwest. The open hearth building of the steel plant in Donora was located about 800 yards down the slope east of the station.

Station No. 11

This station, at an elevation of 910 feet, was located on a graveled street in the southern part of Donora. It was in a residential section with houses on both sides of the street at a higher elevation than the sampling station. The ground sloped upward to the west and downward to the east toward the river. North of the station was a valley which extended up from the river toward the west. The blast furnaces were south at a distance of about 600 yards and the open hearth building was about 500 yards to the northeast.

Station No. 12

This station, at an elevation of 800 feet, was in a residential section of Donora near the boundary line of the steel plant. The open hearth building of the steel plant was about 70 yards directly east and the blast furnace department was about 800 yards south-southwest of the station. Railroad tracks were between the open hearth building and the station. The upward slope of the ground west of the station was rather steep. The main portion of Donora was west, northwest and north of the station.

DISCUSSION OF RESULTS

The total number of samples taken at the 12 air sampling stations was as follows: Sulfur dioxide, 260; total sulfur, 267; total particulate matter, including lead, cadmium, and zinc, 205; chloride, 247; and fluoride, 249. The routine sampling time for these samples was 1 to 2 hours. In addition, 22 samples for chloride and 27 for fluoride were taken at stations No. 4 and No. 9 for periods of 8 to 12 hours. Stations No. 4 and 9 were selected because of their central location in Webster and Donora, respectively; the sampling time was increased in order to increase the accuracy of the determinations. A total of 15 sets of samples was taken outside the Donora area: Four at Charleroi, two at Monessen, and nine at Monongahela City.

All of the samples were submitted to the laboratory for analysis except the samples for sulfur dioxide which were titrated immediately after collection. Because of the very small amounts of particulate matter in some electrostatic precipitator samples, two or more samples were combined from the same station with the same wind direction and speed, within the same sulfur dioxide concentration range and with similar observations. Twenty-six combinations were made involving 56 samples. The samples were weighed individually and then combined for determination of zinc, lead, and cadmium. The amount of zinc, lead, and cadmium in the individual samples was calculated on a proportionate basis of the weight of the individual samples.

In the analysis of the results for variations due to wind direction and speed, the weather bureau data were used, rather than the data on wind direction and speed obtained at the air sampling stations at the time of sampling since these latter readings were influenced by buildings, steep hills, trees, and other obstacles. Moreover, the weather bureau data were taken continuously while the air sampling station data were based on intermittent observations for wind direction and speed. It was noted that for speeds above ten miles per hour the wind direction and speed readings were in close agreement with the weather bureau data. For lower wind speeds the variation was increased, and at speeds of 0–3 miles per hour the greatest differences were noted due to lower sensitivity of the instruments used at the air sampling stations. For all samples taken, the air sampling station data were found to differ from the weather bureau data by an average

of one sector for wind direction, and the wind speed was found to average 3.5 miles per hour higher. For example, if the weather bureau instruments recorded a south wind at 6 miles per hour, the air sampling station data might indicate that the wind was from the southeast or southwest at 9.5 miles per hour.

Contaminants by Station

The results of the analyses of the samples taken at the 12 air sampling stations are shown in the following tables and figures. Sulfur dioxide and total sulfur (as SO_2) are reported in parts of substance per million parts of air by volume (ppm); and total particulate matter, zinc, lead, and cadmium are reported in milligrams of substance per cubic meter of air (mg/m^3).

Table 53 shows a distribution of the concentrations of 6 different atmospheric constituents found at the 12 air sampling stations. It will be noted that all 6 constituents are grouped very markedly in the lower concentration ranges with only a small proportion in the higher ranges. Among the 260 sulfur dioxide samples 9 were in the concentration range of 0.30 to 0.39 parts per million, four were in the range of 0.40 to 0.49 and three were 0.56, 0.58, and 0.61, respectively. Total sulfur showed a wider range of values than sulfur dioxide. Six samples were in the range of 0.50 to 0.59. Above a concentration of 0.60 parts per million values were 0.61, 0.71, 0.74, 0.77, 0.77, and 0.84. Seventy-eight percent of all samples of particulate matter weighed less than one milligram per cubic meter of air. Six samples weighed from 2.5 to 3.4, and the two remaining samples weighed 3.85 and 5.32, respectively. Samples for lead and for zinc showed the greatest number in low values, 91 percent of the former had values of less than 0.0100 milligram per cubic meter of air, and 85 percent of the latter were less than 0.10 milli-

TABLE 53.—*Distribution of atmospheric constituents found at 12 air sampling stations in the Donora area from February 16 through April 27, 1949, by station*

Concentration range	Total number of samples	Station number											
		1	2	3	4	5	6	7	8	9	10	11	12
	Sulfur dioxide (parts per million)												
Total	260	19	20	31	33	23	25	21	20	19	15	17	17
0.00–0.09	145	12	14	17	14	12	15	9	15	12	6	12	7
0.10–0.19	78	3	6	9	12	7	8	9	4	4	5	4	7
0.20–0.29	21	2	0	2	2	4	2	2	1	2	2	0	2
0.30–0.39	9	1	0	2	3	0	0	1	0	0	1	1	0
0.40–0.49	4	0	0	1	1	0	0	0	0	1	1	0	0
0.50 or over	3	1	0	0	1	0	0	0	0	0	0	0	1
	Total sulfur (parts per million)												
Total	267	21	22	31	30	23	25	22	19	19	18	17	20
0.00–0.09	117	11	10	9	6	7	11	13	15	9	8	12	6
0.10–0.19	88	7	5	12	9	7	13	7	3	7	6	4	8
0.20–0.29	24	1	2	6	3	4	1	0	1	1	1	1	3
0.30–0.39	18	1	2	2	4	3	0	1	0	1	3	0	1
0.40–0.49	8	0	1	0	6	1	0	0	0	0	0	0	0
0.50 or over	12	1	2	2	2	1	0	1	0	1	0	0	2
	Total particulate matter (milligrams per cubic meter)												
Total	205	15	19	24	25	20	20	17	12	13	13	13	14
0.0–0.4	95	10	9	8	4	9	7	9	8	8	8	9	6
0.5–0.9	65	3	7	10	6	6	11	4	2	3	3	4	6
1.0–1.4	21	1	1	1	6	4	2	3	1	1	1	0	0
1.5–1.9	9	0	0	2	3	1	0	0	1	1	0	0	1
2.0–2.4	7	0	1	1	3	0	0	1	0	0	1	0	0
2.5 or over	8	1	1	2	3	0	0	0	0	0	0	0	1
	Zinc (milligrams per cubic meter)												
Total	205	15	19	24	25	20	20	17	12	13	13	13	14
0.00–0.09	175	15	17	16	12	15	19	17	12	12	13	13	14
0.10–0.19	13	0	0	3	5	3	1	0	0	1	0	0	0
0.20–0.29	5	0	1	1	1	2	0	0	0	0	0	0	0
0.30–0.39	5	0	0	3	2	0	0	0	0	0	0	0	0
0.40–0.49	3	0	1	1	1	0	0	0	0	0	0	0	0
0.50 or over	4	0	0	0	4	0	0	0	0	0	0	0	0

TABLE 53.—*Distribution of atmospheric constituents found at 12 air sampling stations in the Donora area from February 16 through April 27, 1949, by station*—Continued

Concentration range	Total number of samples	Station number 1	2	3	4	5	6	7	8	9	10	11	12
	Lead (milligrams per cubic meter)												
Total	205	15	19	24	25	20	20	17	12	13	13	13	14
0.000–0.009	186	15	17	19	17	18	19	17	12	12	13	13	14
0.010–0.019	14	0	1	4	6	1	1	0	0	1	0	0	0
0.020–0.029	2	0	0	0	1	1	0	0	0	0	0	0	0
0.030 or over	3	0	1	1	1	0	0	0	0	0	0	0	0
	Cadmium (milligrams per cubic meter)												
Total	205	15	19	24	25	20	20	17	12	13	13	13	14
0.0000–0.0009	149	15	12	16	7	10	13	14	12	12	11	13	14
0.0010–0.0019	15	0	2	1	3	3	3	2	0	0	1	0	0
0.0020–0.0029	12	0	2	2	0	3	3	1	0	1	0	0	0
0.0030–0.0039	8	0	2	2	2	1	1	0	0	0	0	0	0
0.0040–0.0049	1	0	0	0	1	0	0	0	0	0	0	0	0
0.0050 or over	20	0	1	3	12	3	0	0	0	0	1	0	0

gram per cubic meter. The three highest lead samples were 0.0309, 0.0314, and 0.0327, and the four highest zinc samples were 0.52, 0.56, 0.64, and 0.67 milligram per cubic meter. Cadmium concentrations were very low. The three highest values were 0.0163, 0.0164, and 0.0178 milligram per cubic meter of air.

The station to station distribution of concentrations of the various constituents showed variations in pattern which may be roughly correlated with sources of contaminants. Sulfur dioxide showed the most even distribution of the contaminants among the 12 stations. This even distribution may be explained by the large number and wide distribution of sources of sulfur dioxide.

Total sulfur showed a greater concentration near the zinc plant than did sulfur dioxide. No satisfactory explanation of this observation is available from the data obtained.

Total particulate matter showed even distribution except for Stations No. 3 and 4. The even distribution may be explained by the large number and wide distribution of sources. The high values at Stations No. 3 and 4 may have been influenced by nearness to the zinc plant.

Zinc and lead had a very limited distribution for values above the lowest frequency range. The highest values were found near the zinc plant on either side of the river and at relatively low elevations. No values for lead or zinc above the lowest frequency range were found at stations 1, 7, 8, 10, 11, and 12. Cadmium was somewhat more widely distributed by station and showed a special concentration of higher values just across the river from the zinc plant. The high value for cadmium at Station No. 10 was yielded by a sample collected during a temperature inversion. Figure 61 shows the average concentration of zinc, lead, and cadmium for each station arranged in descending order. Stations No. 4, 3, 5, and 2, which are closest to the zinc plant, have the greatest amounts of zinc, lead, and cadmium. Stations No. 10, 7, 1, 12, 8, and 11, which are located at the greatest distance from the zinc plant, show the smallest amount of contamination.

Table 54 shows the stations ranked in decreasing order in accordance with average ratios for the six contaminants. In establishing the ratios the highest average concentration was taken as a base and the ratio of the average concentration for a particular contaminant for each station was calculated on the basis of 100 assigned to the highest concentration.

Station No. 4 shows a value of 100 since the highest average concentration was found for all six constituents at this station. Stations 3, 5, 10, 2, and 12 follow in order. Station No. 11 showed the lowest ratio.

TABLE 54.—*Sampling stations ranked on the basis of 100 chosen to represent the highest average concentration of each constituent*

Station No.	Rank: Average ratio for 6 contaminants	Sulfur dioxide	Total sulfur	Total particulate matter	Zinc	Lead	Cadmium
4	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
3	64. 1	86. 0	79. 2	75. 5	50. 4	68. 2	25. 4
5	54. 9	77. 5	83. 4	45. 3	37. 0	55. 7	30. 6
10	44. 2	100. 0	58. 3	42. 0	6. 4	36. 4	22. 0
2	43. 4	50. 0	70. 8	50. 0	23. 4	42. 1	23. 8
12	42. 2	93. 0	83. 4	46. 5	2. 8	23. 8	3. 4
6	38. 8	71. 5	41. 7	45. 0	13. 3	44. 4	17. 0
7	36. 0	77. 5	45. 8	44. 5	6. 2	35. 2	6. 8
9	34. 4	77. 5	54. 2	38. 5	9. 2	23. 8	3. 4
1	33. 3	86. 0	54. 2	37. 8	3. 4	17. 0	1. 7
8	24. 1	57. 0	29. 2	34. 2	1. 6	19. 3	3. 4
11	22. 8	57. 0	37. 5	25. 8	1. 4	13. 6	1. 7

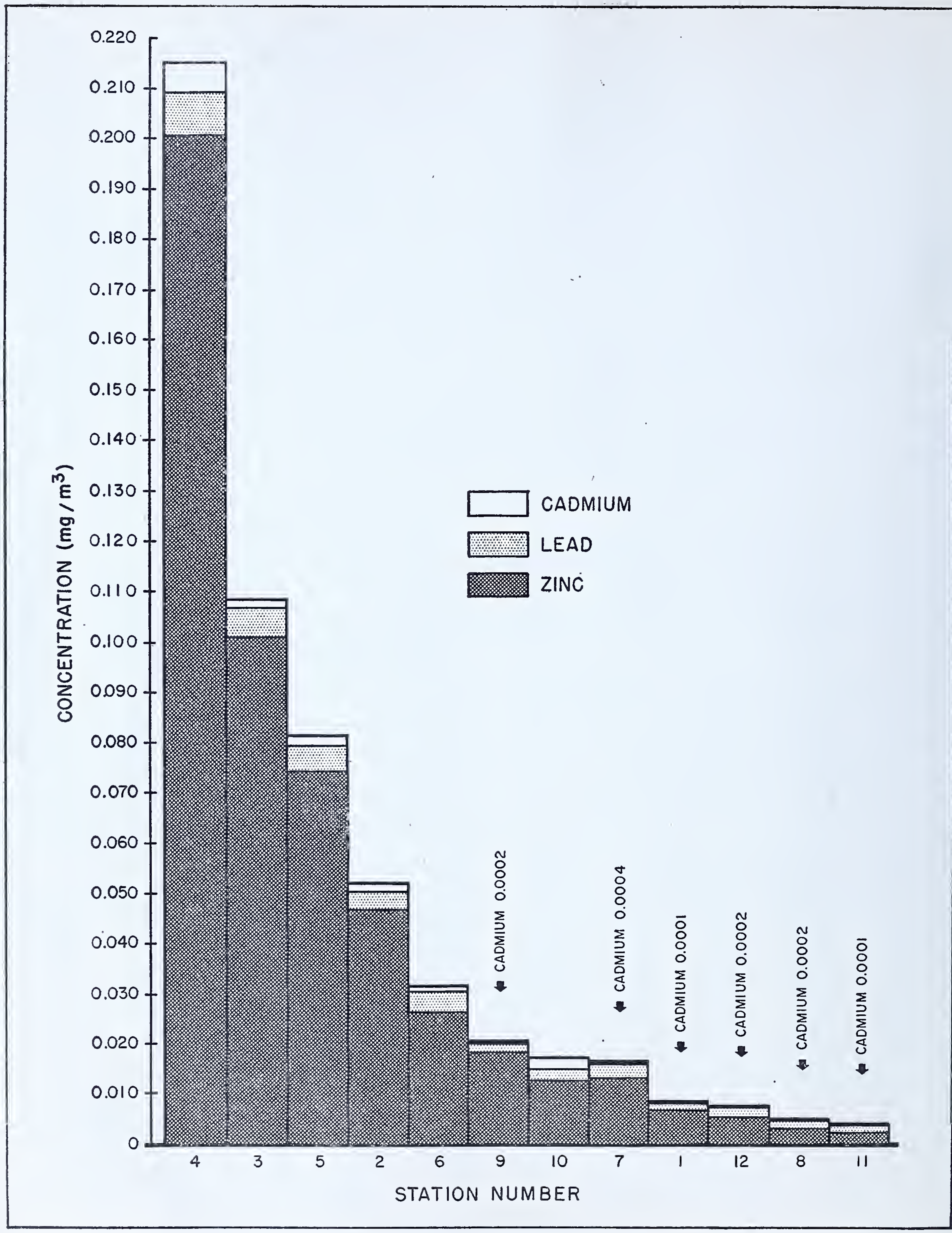


FIGURE 61.—*Average concentrations of cadmium, lead, and zinc by station, arranged in descending order of totals.*

TABLE 55.—*Distribution of atmospheric constituents found in the Donora area from February 16 through April 27, 1949, according to date period*

Concentration range	Total number of samples	Date period: Feb. 16 to Apr. 5	Apr. 6 to Apr. 10	Apr. 11 to Apr. 17	Apr. 18 to Apr. 21	Apr. 22 to Apr. 27
	Sulfur dioxide (parts per million)					
Total	260	143	19	44	40	14
0.00–0.09	145	76	15	28	18	8
0.10–0.19	78	53	2	9	11	3
0.20–0.29	21	10	0	6	5	0
0.30–0.39	9	3	1	0	3	2
0.40–0.49	4	1	1	0	1	1
0.50 or over	3	0	0	1	2	0
	Total sulfur as SO_2 (parts per million)					
Total	267	155	19	42	37	14
0.00–0.09	117	78	10	15	8	6
0.10–0.19	88	54	5	15	10	4
0.20–0.29	24	10	2	5	5	2
0.30–0.39	18	6	2	3	6	1
0.40–0.49	8	3	0	3	2	0
0.50 or over	12	4	0	1	6	1
	Total particulate matter (milligrams per cubic meter)					
Total	205	120	16	26	32	11
0.0–0.4	95	69	9	9	4	4
0.5–0.9	65	40	5	9	6	5
1.0–1.4	21	5	0	4	11	1
1.5–1.9	9	2	2	2	3	0
2.0–2.4	7	3	0	1	3	0
2.5 or over	8	1	0	1	5	1
	Zinc (milligrams per cubic meter)					
Total	205	120	16	26	32	11
0.00–0.09	175	109	15	19	22	10
0.10–0.19	13	5	1	2	4	1
0.20–0.29	5	2	0	1	2	0
0.30–0.39	5	1	0	2	2	0
0.40–0.49	3	1	0	1	1	0
0.50 or over	4	2	0	1	1	0
	Lead (milligrams per cubic meter)					
Total	205	120	16	26	32	11
0.000–0.009	186	116	15	21	24	10
0.010–0.019	14	3	1	4	5	1
0.020–0.029	2	1	0	0	1	0
0.030 or over	3	0	0	1	2	0
	Cadmium (milligrams per cubic meter)					
Total	205	120	16	26	32	11
0.0000–0.0009	149	95	13	14	19	8
0.0010–0.0019	15	9	1	3	1	1
0.0020–0.0029	12	4	1	2	3	2
0.0030–0.0039	8	4	0	2	2	0
0.0040–0.0049	1	1	0	0	0	0
0.0050 or over	20	7	1	5	7	0

Contaminants in Relation to Date Periods

The effect, among others, of plant operation levels on the concentrations of contaminants found in the air of Donora is shown in table 55. The first date period (Feb. 16 to April 5) represents a period of reduced production in the zinc plant, the second and third periods represent major steps in increased production, the fourth period (April 18 to April 21) represents operational conditions and production rates as of October 1948, and the final period is a return toward operational conditions that existed in the first period. The following table, based on table 55, indicates the percentage of samples greater than a certain arbitrary concentration, and shows the influence of plant operation (among others) on concentration of contaminants in the general atmosphere.

Date period	Constituent and concentration					
	Sulfur dioxide, 0.20 or greater ppm	Total sulfur, as SO_2 0.30 or greater ppm	Total particulate matter, 1.5 or greater mg/m³	Zinc, 0.10 or greater mg/m³	Lead, 0.01 or greater mg/m³	Cadmium, 0.002 or greater mg/m³
	Percent of air samples					
1	9.8	8.4	5.0	9.2	3.3	13.3
2	10.6	10.5	12.5	6.3	6.3	12.5
3	15.9	16.7	15.4	27.0	19.2	34.6
4	27.5	37.8	34.4	31.4	25.0	37.5
5	21.4	14.2	9.1	9.1	9.1	18.2

In general, there was a progressive increase in the percentage of samples in the higher ranges in the various date periods reaching a maximum in period 4. This follows the operation of the plant during the date periods as the production was progressively increased to a peak at period 4. The values for zinc and cadmium are similar for date periods 3 and 4 probably due to the fact that production in the zinc plant during period 3 approached the peak production reached in period 4. The marked increase in sulfur dioxide, total sulfur, and total particulate matter between periods 3 and 4 was probably due to changes made in both the steel and zinc plants at the beginning of date period 4. The values in period 5 decreased as the plant returned to curtailed production.

Contaminants in Relation to Time Periods

There are many factors including those of a meterological nature and those related to operation of plants, transportation and domestic facilities which might influence the hour-to-hour change in the concentration of contaminants in the atmosphere.

Table 56 breaks the time of day into four periods and shows the concentration ranges for each period. These periods are: (1) 12:01 a. m. to 6 a. m.; (2) 6:01 a. m. to 12 m.; (3) 12:01 p. m. to 6 p. m.; and (4) 6:01 p. m. to 12 p. m. Slightly less than one-third of the samples were taken during the two night periods which include the time from 6:01 p. m. to 6 a. m. The following table, based on table 56, indi-

TABLE 56.—*Distribution of atmospheric constituents found in the Donora area from February 16 through April 27, 1949, according to time period*

Concentration range	Total number of samples	Time period			
		12:01 a. m.—6 a. m.	6:01 a. m.—12 m.	12:01 p. m.—6 p. m.	6:01 p. m.—12 p. m.
	Sulfur dioxide (parts per million)				
Total	260	43	90	90	37
0.00–0.09	145	17	51	59	18
0.10–0.19	78	18	24	24	12
0.20–0.29	21	3	9	5	4
0.30–0.39	9	2	4	1	2
0.40–0.49	4	1	1	1	1
0.50 or over	3	2	1	0	0
	Total sulfur (parts per million)				
Total	267	45	87	96	39
0.00–0.09	117	16	37	53	11
0.10–0.19	88	16	29	28	15
0.20–0.29	24	6	8	5	5
0.30–0.39	18	3	6	5	4
0.40–0.49	8	2	3	3	0
0.50 or over	12	2	4	2	4
	Total particulate matter (milligrams per cubic meter)				
Total	205	28	72	75	30
0.0–0.4	95	8	38	38	11
0.5–0.9	65	12	18	26	9
1.0–1.4	21	4	7	7	3
1.5–1.9	9	0	3	1	5
2.0–2.4	7	2	1	2	2
2.5 or over	8	2	5	1	0
	Zinc (milligrams per cubic meter)				
Total	205	28	72	75	30
0.00–0.09	175	26	58	66	25
0.10–0.19	13	2	5	4	2
0.20–0.29	5	0	1	3	1
0.30–0.39	5	0	4	1	0
0.40–0.49	3	0	0	1	2
0.50 or over	4	0	4	0	0
	Lead (milligrams per cubic meter)				
Total	205	28	72	75	30
0.000–0.009	186	25	65	69	27
0.010–0.019	14	3	4	6	1
0.020–0.029	2	0	1	0	1
0.030 or over	3	0	2	0	1
	Cadmium (milligrams per cubic meter)				
Total	205	28	72	75	30
0.0000–0.0009	149	20	52	56	21
0.0010–0.0019	15	5	4	5	1
0.0020–0.0029	12	2	4	3	3
0.0030–0.0039	8	0	3	4	1
0.0040–0.0049	1	0	0	1	0
0.0050 or over	20	1	9	6	4

cates the percentage of samples greater than a certain arbitrary concentration.

Time period	Sulfur dioxide, 0.20 or greater ppm	Total sulfur, as SO_2 0.30 or greater ppm	Total particulate matter, 1.5 or greater mg/m³	Zinc, 0.10 or greater mg/m³	Lead, 0.01 or greater mg/m³	Cadmium, 0.002 or greater mg/m³
	Percent of samples					
1	18. 6	15. 5	14. 3	7. 1	10. 7	10. 7
2	16. 6	14. 9	12. 5	19. 4	9. 7	22. 2
3	7. 7	10. 4	5. 3	12. 0	6. 7	18. 7
4	19. 4	21. 1	23. 3	16. 7	10. 0	26. 6

The percentage of samples in the higher concentration ranges was greater during the night periods 1 and 4 than during the day for sulfur dioxide, total sulfur, and total particulate matter. For sulfur dioxide, total sulfur, and total particulate matter the highest concentrations were noted in the period from 6: 01 p. m. to midnight, declined in the forenoon and reached a low point in the afternoon period (noon until 6 p. m.). The higher concentrations for the above contaminants at night may have been due to greater air stability.

Zinc and cadmium show a similar pattern with an increase of higher concentrations in period 2 (6: 01 a. m. to 12 m.). This indicates the influence of plant operations on the concentration of contaminants in the general atmosphere.

Halogens, Oxides of Nitrogen, and Miscellaneous Constituents

Halogens.—One hour samples were taken at the 12 air sampling stations for the determination of chloride and fluoride. Table 57 shows the distribution of concentration of the chloride and fluoride for all of the samples taken.

TABLE 57.—*Distribution of concentrations of fluoride and chloride found in 1-hour samples*[1] *in the Donora area from Apr. 11 through Apr. 27, 1949*

Concentration range (milligrams per cubic meter)	Number of fluoride samples	Concentration range (milligrams per cubic meter)	Number of chloride samples
Total	249	Total	247
0.000–0.009	[2] 236	0.00–0.09	[3] 221
0.010–0.019	7	0.10–0.19	11
0.020–0.029	2	0.20–0.29	5
0.030 or over	4	0.30 or over	10

[1] Average volume 1.7m³.
[2] 224 of these were 0.000.
[3] 199 of these were 0.00.

The table indicates that about 90 percent of the chloride values and about 95 percent of the fluoride values are in the lowest concentration range. Most of the values in the lowest concentration range of both chloride and fluoride were zero.

Since so many of the 1-hour samples (average volume 1.7 m³) were negative, samples of 5 or more hours (average volume 14.7³) were collected during the period from April 11 to April 27 in order to increase the accuracy of the determination. Stations No. 4 and 9 were selected for these samples because of their central location in Webster and Donora, respectively, and because of the availability of power sources at these points. Table 58 shows the distribution of concentration of chloride and fluoride found in these samples. The values found for both constituents are of a very low order of magnitude. The maximum concentrations found for these samples were for chloride, 0.062 and for fluoride, 0.0059 milligram per cubic meter of air.

TABLE 58.—*Distribution of concentrations of fluoride and chloride found in the 5 or more hour samples*[1] *taken at air sampling stations 4 and 9 in the Donora area from Apr. 11 through Apr. 27, 1949*

Concentration range (milligrams per cubic meter)	Number fluoride samples: Station 4	Number fluoride samples: Station 9	Concentration range (milligrams per cubic meter)	Number chloride samples: Station 4	Number chloride samples: Station 9
Total	11	16	Total	4	18
0.0000–0.0009	4	4	0.000–0.009	0	4
0.0010–0.0019	3	6	0.010–0.019	0	5
0.0020–0.0029	3	4	0.020–0.029	0	6
0.0030 or over	1	2	0.030 or over	4	3

[1] Average volume 14.7 m³.

Oxides of nitrogen.—As stated previously in *Determination of Contaminants*, four-liter samples were taken by air displacement for the determination of oxides of nitrogen. Table 59 shows the distribution of concentrations of oxides of nitrogen found at all stations. The concentrations of the oxides of nitrogen found were of a very low order of magnitude.

TABLE 59.—*Distribution of oxides of nitrogen concentrations (parts per million) in the general atmosphere in the Donora area*

Concentration range (parts per million)	Number of samples
Total	33
0.00–0.19	[1] 23
0.20–0.39	3
0.40–0.59	6
0.59 or over	1

[1] Eleven of these were 0.00.

Miscellaneous samples.—During the atmospheric sampling portion of the survey, tests were made for chlorine, carbon monoxide and hydrogen sulfide. The test for chlorine consisted of bubbling the air through an orthotolidine solution in a midget impinger. National Bureau of Standards carbon monoxide detector tubes and Mine Safety Appliances hydrogen sulfide detector tubes were used in the tests for carbon monoxide and hydrogen sulfide.

Although a number of tests were made for the above gases throughout the sampling period from February 16 to April 27, no positive results were obtained.

Results Obtained by Thomas Recorder

The Thomas automatic recorder is an instrument designed to give a continuous recording of the change in conductivity caused by any material which would ionize in a very dilute sulfuric acid solution containing a small amount of hydrogen peroxide. In this particular study the following substances may be included among the materials which would give a reading on the recorder: sulfur dioxide, sulfur trioxide, soluble salts and oxides of nitrogen.

Figure 62 shows the results of the analyses of samples collected for the determination of sulfur dioxide (iodometrically) and total sulfur (turbidimetrically) and the values recorded at the same time by the Thomas automatic recorder, all expressed as SO_2 in parts per million parts of air by volume. The average values for sulfur dioxide are lowest, total sulfur intermediate, and the automatic recorder highest. The higher average values for the automatic recorder can be attributed to other materials which affected conductivity in addition to sulfur dioxide. The total sulfur averages are higher than the sulfur dioxide averages since they include sulfur dioxide, other compounds containing sulfur, and elemental sulfur.

The Thomas automatic recorder was in operation during five inversion periods. During the first inversion period, from 5 a. m. to 9 a. m. on March 25, only a slight build-up was shown on the recorder with the values varying from 0.11 to 0.28 ppm as SO_2. The inversion period of 8 p. m., March 29 to 9 a. m., March 30, showed a considerable build-up as the values varied from 0.17 to 0.81 with an average of 0.42 ppm. During the inversion period from 9 p. m., April 11, to 8 a. m., April 12, there was no build-up since the values ranged between 0.10 and 0.12 ppm. During the inversion period on the night of April 20 values were recorded from 0.16 to 0.62 with an average of 0.40 ppm. During the inversion period on the night of April 26 values were recorded from 0.26 to 0.35 with an average of 0.30 ppm.

Figure 63 shows the chronological order of the average daily results from the Thomas automatic recorder expressed in parts of sulfur dioxide per million parts of air by volume. Also shown are the daily average wind direction and speed, temperature, and air sampling stations. The values range from 0.06 to 0.70 ppm as SO_2. Six peaks occurred with values ranging from 0.40 to 0.70 ppm. Most of these peaks occurred while the recorder was at station No. 4 with a northwest wind at high speeds (above 10 miles per hour).

The average values of sulfur dioxide were higher at station No. 4 than at the other stations which agrees with the results of the other field samples for sulfur dioxide and total sulfur.

Figure 64 shows curves prepared by plotting half-hour recorder readings. Two curves are presented for each of three stations, namely, Nos. 1, 2, and 4. One curve shows typical low values and the other typical high values. Also shown are wind direction and speed. These curves indicate the range and fluctuation of concentrations which were found during various 24-hour periods for the three stations.

Particulate Matter From Home Filters

Samples of particulate matter were obtained from five home filters in the Donora area and one from Monessen. One of the filters from the Donora area had been cleaned just prior to the October smog and the sample obtained immediately after the smog. This sample, thus, contained essentially only material collected from the air during the smog.

Three samples were obtained that covered a period which included before, during, and after the October smog and two represented material collected after the smog; one of these samples was from Monessen. These samples were analyzed to determine if there were any major differences either qualitatively or quantitatively in the composition of the material. A spectrographic analysis showed silicon, iron, zinc, magnesium, and aluminum to be major constituents, and copper, lead, manganese, calcium and cadmium, among others, to be minor constituents. There did not appear to be any significant differences in the composition of the various samples, including the sample from Monessen.

The samples were also analyzed chemically for nitrate, chloride, fluoride and sulfur. There did not appear to be any significant differences as regards nitrate, chloride and fluoride. The amount of sulfur, however, varied significantly, the largest percentage being found in the sample collected during the smog and the smallest percentage in the samples collected after the smog. An intermediate value was obtained for the samples covering a period which included before, during and after the smog. The significance of this finding cannot be evaluated on the basis of the data available, but it is believed that the subject warrants further study to provide additional data on which a proper evaluation can be based.

Contaminants in Communities Adjacent to Donora

A few samples were taken outside the Donora area in Charleroi, Monessen, and Monongahela City. Table 60 shows the results of the analyses of these samples. The

TABLE 60.—*Concentration of contaminants in communities adjacent to Donora*

Wind direction and speed (mph)	Sulfur dioxide (ppm)	Total sulfur as SO_2, (ppm)	Total particulate matter (mg/m³)	Zinc (mg/m³)	Lead (mg/m³)	Cadmium (mg/m³)
MONESSEN-CHARLEROI						
NW–18	0.02	0.02	IA	IA	IA	IA
NE–3	.10	.85	0.435	0.0144	0.0020	0.0004
NW–3	.02	.08	.364	.0026	.0010	.0001
E–3	.09	.11	.500	.0186	.0021	.0005
NW–4	.20	.22	.718	.0157	.0037	.0001
SW–10	.17	.03	.284	.0017	.0007	.0001
MONONGAHELA CITY						
SW–3	0.23	0.20	0.320	0.0014	0.0004	0.0001
SE–3	.22	.13	.624	.0195	.0062	.0009
SE–1	.12	.02	.222	.0069	.0022	.0003
N–5	.05	.04	.470	.0025	.0006	0
SE–3	.14	.07	.510	.0161	.0051	.0007
NE–3	.04	.06	.428	.0025	.0011	0
NW–16	.11	.04	.105	.0007	.0004	0
N–6	.11	.06	.540	.0028	.0011	.0001
NW–3	.21	.11	.706	.0047	.0023	.0002

ppm: Parts of substance per million parts of air by volume.
mg/m³: Milligrams of substance per cubic meter of air.
IA: Insignificant amount.
mph: Miles per hour.

number of samples is not large enough to permit a comparison with the samples collected in the Donora area. However, the results do give some information of the concentration of contaminants found outside of Donora.

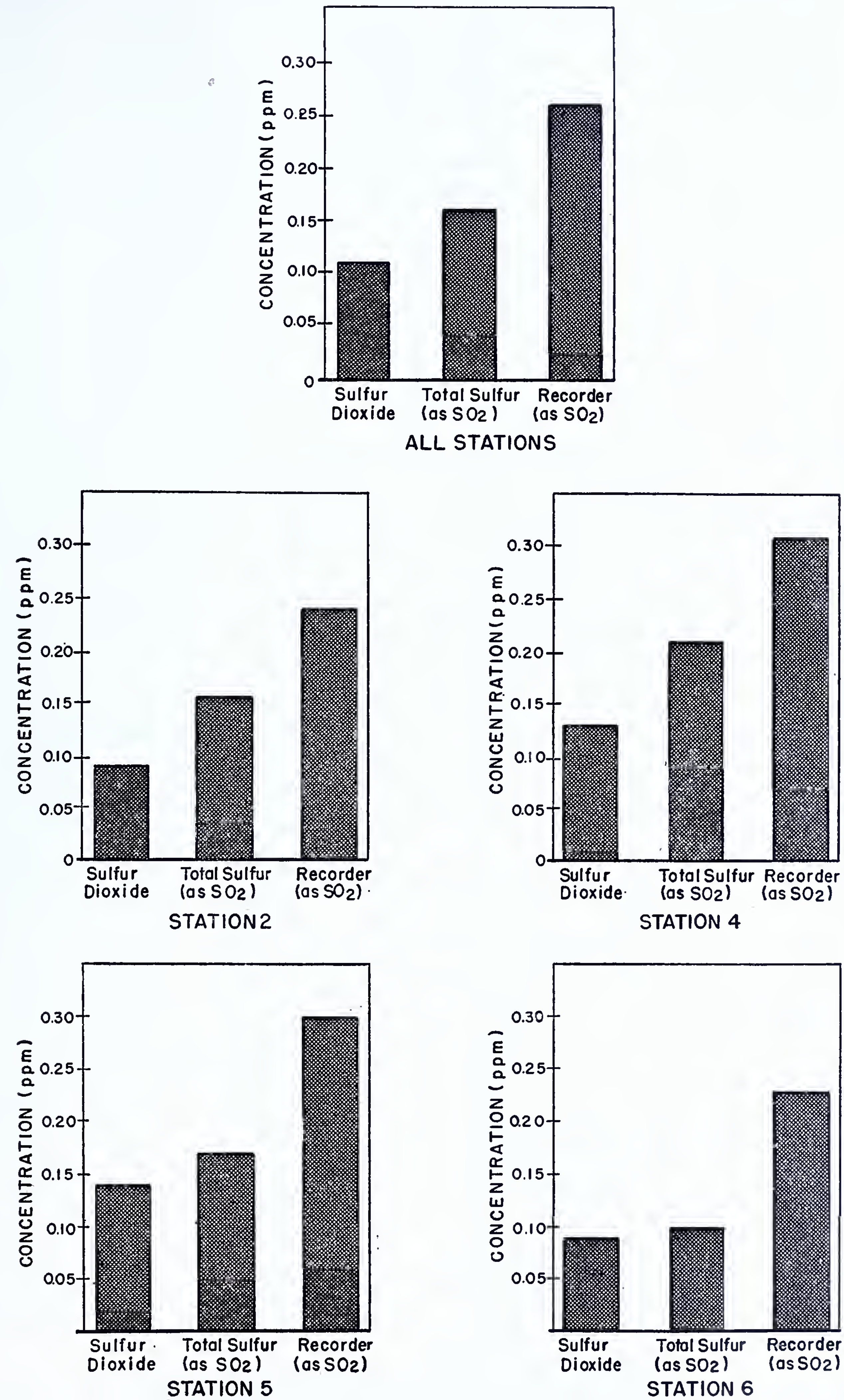


FIGURE 62.—*Results of analyses of samples collected for determination of sulfur dioxide (iodometrically) and total sulfur (turbidimetrically), and values recorded at the same time by the Thomas automatic recorder; all expressed as sulfur dioxide in parts per million parts of air by volume.*

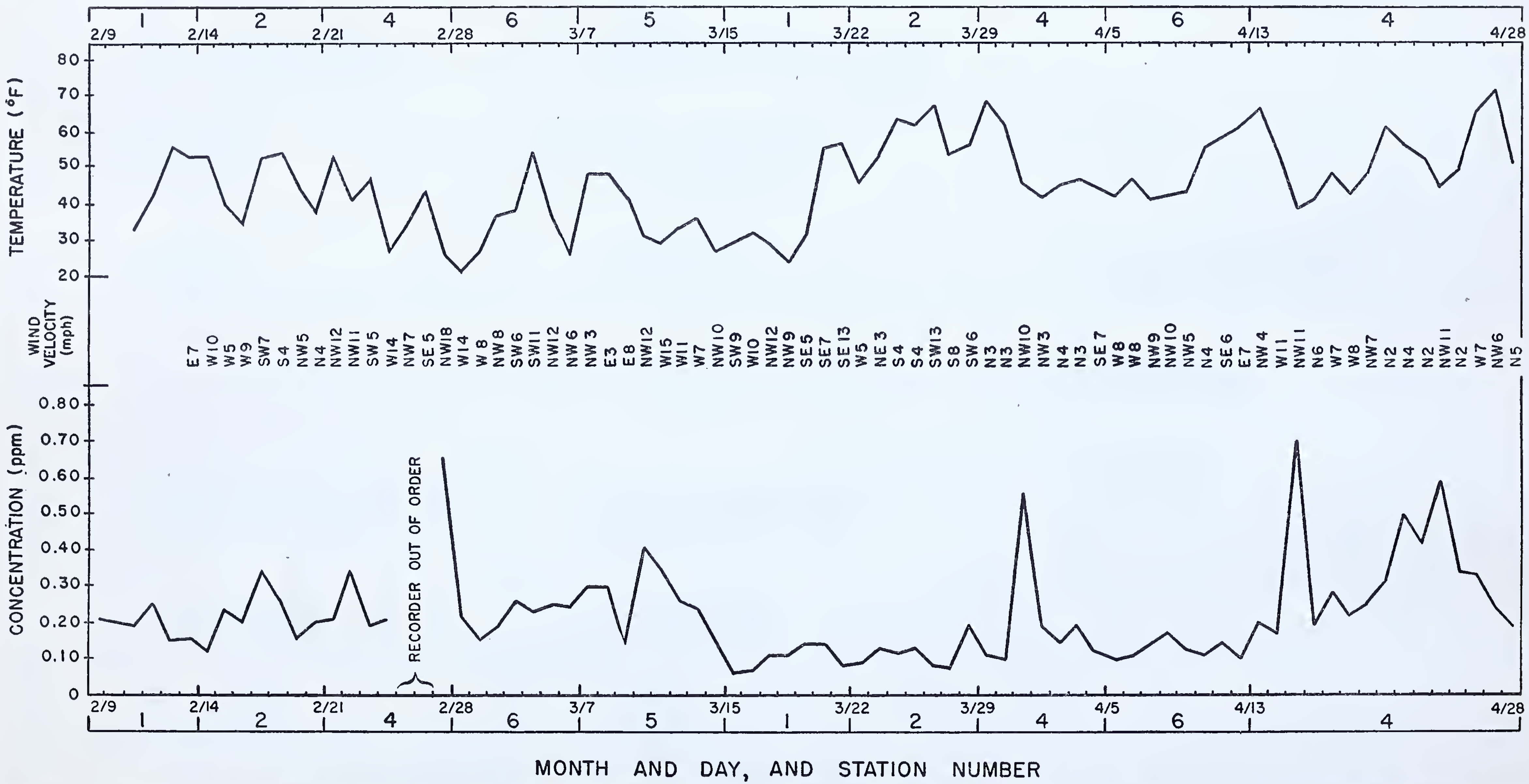


FIGURE 63.—*Variation with time in values recorded by the Thomas automatic recorder expressed as sulfur dioxide in parts per million parts of air by volume, together with station number and daily average wind velocity and temperature for the period February 9–April 28, 1949.*

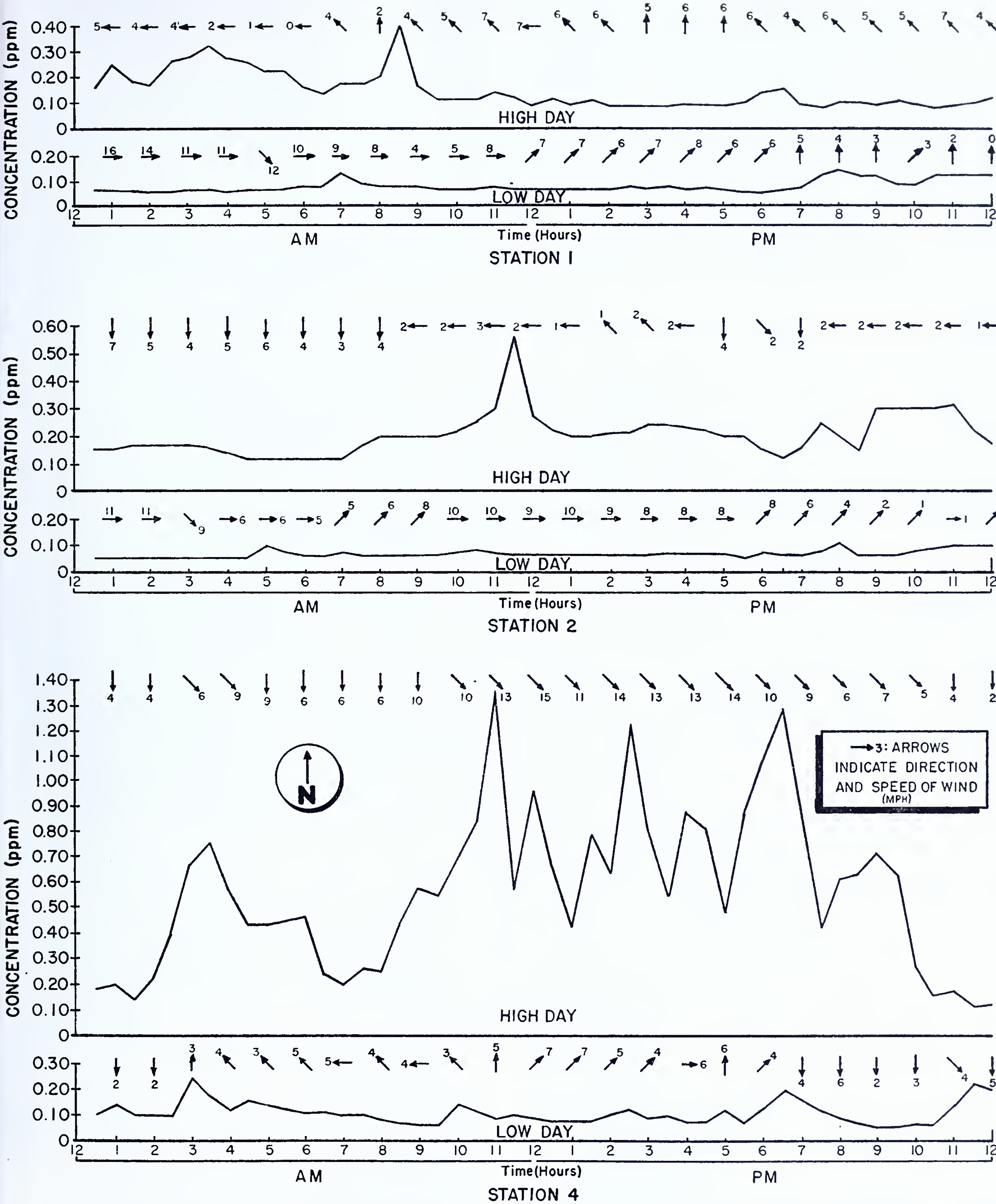


FIGURE 64.—*Variation over 24 hours in values recorded at half-hour intervals by the Thomas automatic recorder, expressed as sulfur dioxide in parts per million parts of air by volume, together with hourly wind velocities for typical high and low days at each of three air-sampling stations.*

METEOROLOGICAL INVESTIGATION

W. H. Hoecker, Jr.

FOREWORD

Gases and small particles released into the atmosphere move as a part of the atmosphere and are therefore subjected to all of the complex whirls and eddies that characterize the movement of air near the ground. If there were no means of removing the contaminants from the surface layer of air in the neighborhood of the emission point the atmosphere in that area would soon become intolerable for animal and plant life. The atmosphere exercises its cleansing action by means of the winds which move material horizontally away from the emission point and by vertical currents associated with convection or mechanically caused turbulence which enable the contaminants to be removed aloft. However there are certain regions where, because of the occasional presence of special meteorological conditions, the normal cleansing action of the atmosphere is temporarily inactive. This occurs when the winds are so light and the vertical motions so insignificant that the contaminable material accumulates to annoying or even dangerous concentrations.

With the growing industrialization attending modern civilization the pollution of the atmosphere by industrial byproducts is a matter of increasing concern to all of us. More and more localities are showing an awareness of the importance of reducing atmospheric pollution. Most efforts are naturally concentrated on reducing the output of contaminants at the source. But even so an irreducible minimum of effluent must still be released and thus come under control of atmospheric motions. That the meteorologist can contribute to a system of "meteorological control" of effluent release was shown recently in the successful control system established in smelter plant operations in the Columbia River Valley at Trail, British Columbia.

When the Weather Bureau was requested to assist the Public Health Service in its investigation at Donora, Pennsylvania, we felt that this was an unique opportunity to be of service and at the same time to increase our knowledge of the general problem of atmospheric pollution and its relation to micrometeorology. It has been a pleasure for the Weather Bureau to be associated with this project and it is hoped that following meteorological sections will contribute to the solution of the problem of minimizing atmospheric pollution.

F. W. Reichelderfer
Chief, U. S. Weather Bureau

The tragic results of the Donora, Pa., smog episode of October 30, 1948, led the United States Public Health Service, at the invitation of the Division of Industrial Hygiene of the Pennsylvania State Department of Health, to investigate causes of the disaster. Realizing the critical importance of weather in producing smog conditions, the Public Health Service requested the United States Weather Bureau to study the micrometeorology of the Donora area. The micrometeorological investigation was conducted simultaneously with Public Health Service's determination of the kind and quantity of airborne combustion products in the Donora area during the period February 14 to April 28, 1949.

The purpose of the meteorological study was (1) to investigate the physical processes which cause rapid dilution of the industrial airborne waste products or their retention in dangerous concentrations in the Monongahela River Valley at Donora; (2) to determine the general weather type favorable to retention of airborne contaminants in the Donora area in

order that the onset of these periods may be forecasted; and (3) to correlate the meteorological findings and the air sampling analyses.

The purpose of this report is to describe activities and findings of the United States Weather Bureau at Donora. The topics discussed include distribution and instrumentation of weather stations in the area, weather elements recorded, micrometeorological findings from the observational data, comparison of the meteorological results with the meteorological situation of the Donora smog episode, and conclusions drawn from the meteorological investigation.

METEOROLOGICAL TERMINOLOGY

Much of the discussion of the Weather Bureau's activities at Donora involves meteorological terminology which may not be familiar to all readers. For the convenience of the readers, a few of the most important terms are defined as follows (*1*).

1. *Smog.*—A portmanteau word contracted from *smoke* and *fog*. Thus, smog is smoke-polluted fog.

2. *Lapse rate.*—In general the rate of change in the value of any meteorological element with elevation. Usually restricted to rate of decrease of temperature with elevation. The temperature lapse is usually positive, that is, the temperature falls off with elevation; it is negative when the temperature increases with height.

3. *Adiabatic lapse rate.*—A lapse rate (see above) equal to the rate of decrease of temperature of a sample of adiabatically expanding air. For dry (that is, unsaturated) air it is approximately 5.5° F. per 1,000 feet.

4. *Potential temperature* (Θ).—The temperature which air would reach were it reduced adiabatically to the standard pressure of 1,000 millibars. In the text the symbol Θ indicates potential temperature and the symbol $d\Theta/dz$ indicates the change in potential temperature with height. The relations of the change in potential temperature with height to the more familiar terms used to describe temperature lapse rate in the atmosphere should be kept in mind.

These are:

a. Super-adiabatic lapse rate: $d\Theta/dz<0$.

b. Adiabatic lapse rate: $d\Theta/dz=0$.

c. Normal lapse rate: $0<d\Theta/dz<5.5$°F./1,000 feet.

d. Isothermal lapse rate: $d\Theta/dz=5.5$° F./1,000 feet.

e. Inversion: $d\Theta/dz>5.5$° F./1,000 feet.

5. *Stability.*—A state of equilibrium of the atmosphere in which the vertical distribution of temperature is such that an element of air will resist vertical displacement. In dry air the lapse rate (see above) necessary for stability is less than the dry adiabatic; in saturated air, the lapse rate must be less than the saturation adibatic. Quantitatively, stability (S) may be determined from $S=\frac{g}{\Theta}d\Theta/dz$ (*2*). For the purposes of this report, g, the acceleration of gravity, may be considered constant, so that $S\propto\frac{1}{\Theta}d\Theta/dz$. The range of values of Θ for data used in this report is small, hence $d\Theta/dz$ is adopted here as a measure of stability. Any increase with height of potential temperature gives a thermally stable atmosphere but the degree of stability is proportional to the rate of change of potential temperature with height. In this report the following terms will be used to describe stability conditions of the air:

a. "Very stable" refers to a layer of air in which the change in temperature with increased elevation is positive and potential temperature increases with elevation at a rate greater than 5.5° F. per 1,000 feet. This condition is commonly referred to as an inversion.

b. "Moderately stable" refers to a layer of air having no change of temperature with height, commonly referred to as an isothermal layer. Here the increase of potential temperature with height is 5.5° F. per 1,000 feet.

c. "Stable" refers to a layer of air in which the rate of change of temperature with height is between zero and minus 5.5° F. per 1,000 feet. This is equivalent to a rate of change of potential temperature with height greater than zero and less than 5.5° F. per 1,000 feet.

d. "Neutrally stable" refers to a layer of air in which the decrease of temperature with height is 5.5° F. per 1,000 feet, or rate of change of potential temperature with height is zero.

e. "Unstable" refers to a layer of air in which the temperature decreases with height at a rate greater than 5.5° F. per 1,000 feet. This condition is often referred to as a superadiabatic lapse rate. The rate of change of potential temperature is negative with height and the layer of air is mechanically unstable.

6. *Shear of wind.*—The rate of change of wind velocity (speed and direction) with distance. Distinction is usually made between the vertical wind shear, dv/dz and the horizontal wind shear, dv/dx, where v is the total horizontal wind velocity, z is the vertical direction and x is the horizontal directional normal to v. The wind shear may be expressed by the shear vector, which is the vector difference of the wind velocity at two points, divided by the distance between them.

7. *Convection.*—In physics, the circulation in a fluid of nonuniform temperature, resulting from differences in density and the action of gravity. In meteorology, the process whereby a circulation is created and maintained within a layer of the atmosphere, due either to surface heating of the bottom of the layer or to cooling at its top, and consisting in the sinking of relatively heavy air and the consequent forcing up of air which, volume for volume, and under the same pressure, is relatively light. In addition to this process, often called "thermal convection," some meteorologists recognize "mechanical convection," in which air is forced to rise on the windward side of an obstacle and to descend on the leeward side.

8. *Turbulence.*—In the atmosphere, the irregular local transitory variations in the general airflow, which are manifested by gustiness. Such irregular air motion is made up of a number of small eddies that travel with the general air current, superimposed on it.

9. *Geostrophic wind.*—A steady horizontal air motion along straight, parallel isobars in an unchanging pressure field, with gravity the only external force, and in a direction perpendicular to that in which the Coriolis force (due to the earth's rotation) and the pressure gradient force are acting equally and oppositely.

10. *Aerological soundings.*—Temperature-altitude determination in the upper air made by radio transmitter units

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coupled with temperature, pressure, and humidity measuring devices. The assembly is carried to high altitude by a helium-filled balloon.

11. *Anticyclone.*—An area of relatively high pressure with closed isobars, the pressure gradient being directed from the center so that the wind blows spirally outward in a clockwise direction in the northern hemisphere, counterclockwise in the southern. There are two kinds of anticyclones, cold and warm. Cold anticyclones are formed when air over a restricted area is cooled from below. Since pressure decreases rapidly with height in cold air, the isobaric surfaces over the area where the cooling is occurring are lowered relative to the surrounding (noncooled) air. This lowering of the isobaric surfaces means that a low center is undergoing deepening at some level above the anticyclone; and the high surface pressure in the cold anticyclone is due to convergence, or piling up of air, in the low center aloft. Cold anticyclones consequently, are comparatively shallow, and are capped by a low pressure center. Warm anticyclones on the other hand, are deep systems, and high pressure prevails far up into the atmosphere.

12. *Anticyclogenesis.*—The sum of the processes which create and develop a new anticyclone or intensify an already existing one (*3*).

13. *Coriolis force.*—In modern meteorology, the name usually applied to the deflecting influence of the earth's rotation on winds; owing to this influence, winds in the northern hemisphere are deflected to the right and in the southern hemisphere, to the left.

DISTRIBUTION AND INSTRUMENTATION OF WEATHER STATIONS

Since the closest first-order weather station was located at Pittsburgh airport, 12 miles away, the initial task facing Weather Bureau meteorologists detailed to Donora late in January 1949, was the installation of a network of automatically recording weather stations to provide observations for the micrometeorological investigation. The distribution of stations in the network was determined primarily from a study of the topography of the area. The principal terrain features which determined the station locations are described briefly here.

Donora is situated on the west slope of the relatively deep and narrow valley of the Monongahela River about 26 miles south-southeast of the heart of Pittsburgh. Webster, a neighboring village, is situated on the eastern slope of the valley opposite Donora. The Monongahela follows a meandering course as it flows northward to join the Allegheny near Pittsburgh as shown in Map 1, on page 1. At Donora the river makes a horseshoe bend with the city on the inner side of the bend. At this point the river flows approximately south to north; the ends of the horseshoe lie in an east-west direction. The generally steep valley walls vary considerably in grade and are opened at many places by deep ravines. The general hilltop level, at an elevation of 1,250 to 1,300 feet above mean sea level, rises 450 to 500 feet above the river.

From the study of the topography, it was decided that at least eight automatically recording weather stations would be necessary to determine the micrometeorology of the river valley at Donora. These eight stations were distributed as shown in figure 67. Six of the stations were arranged in a line across the valley at hilltop, midslope, and valley-bottom levels on each side. This line intersected the position of the Donora Cooperative Station with wind instruments 150 feet above ground level at the west bank of the river near the center of the valley. This arrangement of stations provided observations for construction of vertical cross sections showing the wind structure of the valley. The other two stations were placed on the east valley wall at the sharp bends in the river, one each north and south of Donora. Wind observations from these two stations and the Cooperative Station made possible the study of wind components along the valley.

Three minor stations were established (see fig. 67) in addition to the eight major ones described above. Two of the minor stations were placed opposite to and at about the same height as the two major stations at the river bends. The third minor station was placed in the largest ravine entering the valley east of Donora. The minor stations, recording temperature only, were used to help complete the horizontal thermal pattern of the valley.

Meteorological quantities recorded at the eight major stations included wind direction and speed, temperature, relative humidity, and rainfall. Wind direction and speed were recorded on a standard Weather Bureau triple register operated on a conventional automobile 6-volt storage battery. The wind vane was a standard Friez make which indicates to 8 points; the anemometer was a 3 cup Friez Model 349, requiring no correction for low wind speeds. Temperature and relative humidity, recorded on a single chart, were measured by a Bourdon tube and hair hygrometer, respectively. The instrument is manufactuered by the Instrument Corporation, Baltimore. Weatherproof boxes, supported on stakes about 1 foot above the ground, housed the battery and triple register. A Standard Cotton Region Shelter containing the hygrothermograph was secured to the top of the weatherproof box. Thus, the instrument shelter was about 4½ feet above the ground. All doors to the weatherproof shelter boxes faced to the east. As was anticipated, this orientation protected the observer and instruments when charts were being changed during windy and rainy periods. The rain gauges of the automatic accumulative weighing bucket type, Friez No. 775, were placed about 30 feet from the shelter boxes.

Unfortunately, reliable river water temperatures were not obtainable.

MICROMETEOROLOGY OF THE MONONGAHELA RIVER VALLEY, VICINITY OF DONORA

The micrometeorology of the Donora area revealed by observations from the station network is discussed in this section. First, a description is given of the general wind mechanism of the valley as indicated by average data. Then, against this background of average conditions, the thermal and wind structures in the valley and the associated macrometeorological conditions are discussed for each of three classes into which observations were grouped.

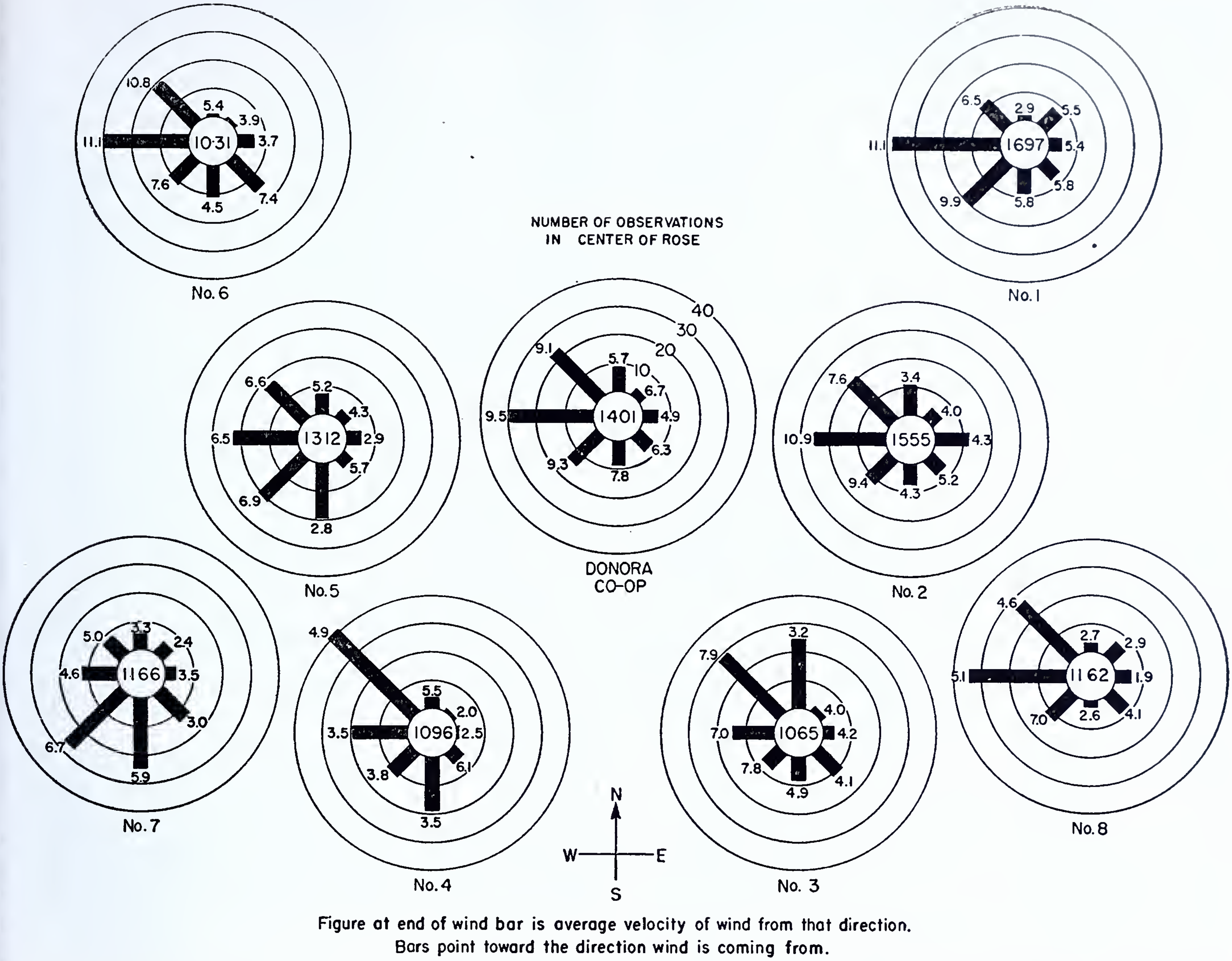


FIGURE 65.—*Percentage frequency of wind directions and average speed for each direction for all wind observations taken during the spring 1949, Donora investigation.*

General Wind Mechanism of Valley

The average wind mechanism of the valley at Donora may be described with the aid of figure 65, wind roses for all stations.[1] The wind rose for each station shows the wind direction frequencies as percentages of the total number recorded and the average wind speed in miles per hour for each direction. About one-third of all wind directions are from the west at hilltop level. The midslope stations (Nos. 2 and 5) show the effect of the valley in channeling the winds to the approximate direction of the valley at this location which is from north-northwest to south-southeast. Station No. 5 is to the east of a NE-SW ridge which probably accounts for the higher percentage of southwest and south directions there. The valley floor stations (Nos. 3 and 4) show more definite effects of channeling, No. 3 having directions about evenly divided between north and northwest and No. 4 showing a high percentage of northwest directions. The high percent of directions from NW and S at station No. 4 can be explained by the narrow channel in which the station is situated. Close by to the west of this station are the tall sheds of an industrial plant which are aligned NNW-SSE, and further to the west is a high bank aligned in almost the same direction. The Donora Cooperative Station with wind instruments at about midvalley height near the river shows a higher percentage of winds from the west but with almost as high a percentage from the northwest. It compares very closely with station No. 2 (also at about midvalley height). Station No. 7 at the river bend to the south of Donora, with its high percentage of directions from the southwest and south, shows the turning effect of the valley at that location. No. 8 has a higher percentage of directions from the west with a secondary maximum from northwest, the approximate direction of the valley there, showing the turning of the valley wind. The combined effect of Nos. 7 and 8 would indicate some horizontal convergence of winds toward Webster. Five of the nine stations show the highest average wind velocity for the direction of highest frequency.

A general picture of the wind speed structure in the valley

[1] See fig. 67 for station locations.

at Donora is given by table 61 showing the frequency with which all stations had hourly average speeds in the given speed classes. The concentration of higher frequencies of

TABLE 61.—*Frequencies of hourly average wind speeds all directions*

Station	Speed class (miles per hour)					
	0–5	6–10	11–15	16–20	21–25	26–30
1	532	546	287	187	40	5
2	706	508	294	80	7	
3	893	526	171	4		
4	1, 159	412	24			
5	787	659	135	14		
6	580	523	322	130	28	12
7	920	596	67	12		
8	1, 028	494	70	3		
Donora Cooperative	506	612	343	76	8	

lower speeds is seen in the lower level stations and river bend stations. Of interest is the fact that hilltop station No. 1 and the Donora Cooperative Station had higher frequencies of speeds in the 6–10 miles-per-hour class than in the 0–5 miles-per-hour class. Not all stations recorded the same number of observations as No. 1, so the remainder of the frequencies were adjusted so that the total number of observations at each station equals that of No. 1.

It must be emphasized that these data and the results are for one season of one year. Additional data could change the pattern considerably.

Micrometeorology for Special Periods

A more detailed picture of the micrometeorological conditions in the valley than that given by the average wind data in the preceding discussion, was obtained by grouping data for the following three special classes of observational periods:

1. Periods from 2100 EST to 1200 EST the following day, in which there was evident attenuation of visibility by smoke during the morning. These periods are referred to as "smoky mornings."
2. Periods from 2100 EST to 1200 EST the following day, in which mornings were nonsmoky with calm to light winds. These periods are called "nonsmoky, calm mornings."
3. Days or periods (of 8 hours or more) with wind speeds that averaged greater than 10 miles per hour, with a one-hour maximum average speed of 15 miles per hour during the period. These are called "windy periods."

Each of these three classes of data was analyzed to determine:

1. Thermal structure of the valley.
2. Thermal structure above hilltop.
3. Wind mechanisms in the valley.
4. Macrometeorological type of situation associated with the class.

The findings for each of the classes of data are now discussed.

Smoky mornings.—Smoky mornings were marked by a decrease of visibility in the valley at Donora due to smoke. They were classified as very smoky, moderately smoky, and smoky, with visibility limits of 0 to ¼ mile, greater than ¼ to ¾ mile, and greater than ¾ mile to 1½ miles, respectively.

Smoky mornings sometimes started with accumulation of smoke as early as 2000 or 2100 EST the night before. They were always accompanied by valley winds of about 3 miles per hour or less and cloudless skies during the early part of the night. A total of 17 mornings had reduced visibilities due to smoke during the spring, 1949 investigation, and only one of these had accompanying fog, the fog was apparently caused by evaporation of rain in the valley trapped air. They were distributed as follows:

Very smoky	7
Moderately smoky	4
Smoky	6

Table 62 shows the occurrences of smoky mornings under varying thermal conditions in the valley. The table shows

TABLE 62.—*Smoky mornings. Occurrence of various visibility classes under Valley thermal structures*

Class	Valley thermal structures		
	Very stable ($d\theta/dz > 5.5°$ F./1,000 feet)	Moderately stable ($d\theta/dz = 5.5°$ F./1,000 feet)	Stable ($0 < d\theta/dz < 5.5°$ F./1,000 feet)
Very smoky	6	1	0
Moderately smoky	2	2	0
Smoky	0	2	4

good agreement of visibility limits with various degrees of stability. The average maximum stable thermal structure observed in the valley is shown in the vertical cross section (fig. 66) and in the horizontal contour chart of the Donora

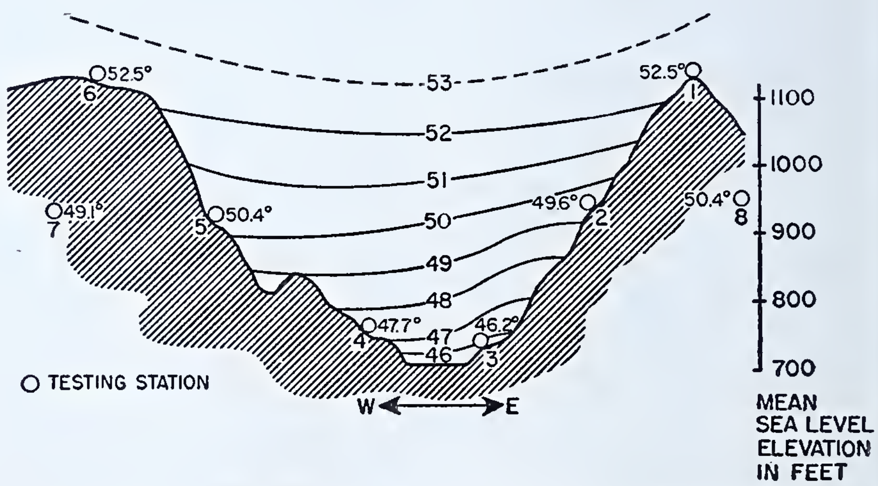


FIGURE 66.—*Average very stable (inversion) thermal structure in valley for radiation nights. Temperatures used were at time of maximum stability.*

area (fig. 67). The average maximum temperature difference between hilltop and valley was 6° F. (*4*).

Upper air soundings from the Allegheny County Airport Weather Bureau Station (Pittsburgh) were considered as representative of the thermal structure of the atmosphere above hilltop level at Donora. Examinations of these showed that a very stable layer of air at hilltop at Donora was not essential to produce a smoky morning. Table 63 shows the

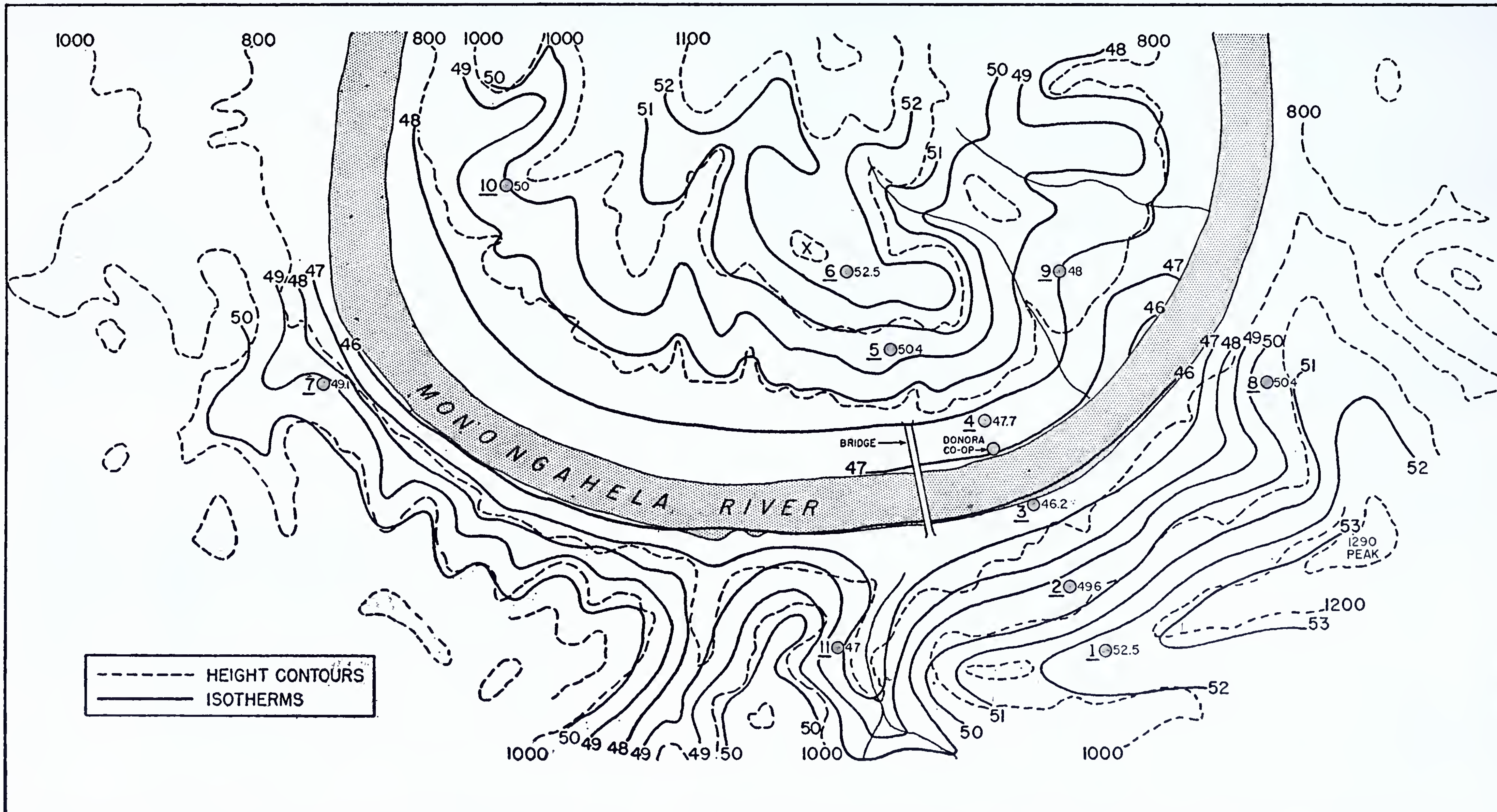


FIGURE 67.—*Horizontal plot of Figure 66 showing conformation of temperature layers to the topography. Weather Bureau Station locations are shown also.*

TABLE 63.—*Smoky mornings. Occurrences of various visibility classes under various heights of very stable layer in upper air*

Class	Height of base of very stable layer ($d\Theta/dz>5.5°$ F./1,000 feet)		
	Hilltop height	100–500 feet above hilltop [1]	Above 1,000 feet [1]
Very smoky	5	1	1
Moderately smoky	1	1	2
Smoky	0	[2] 2	4

[1] Condition existed either at 2000 EST day before or at 1000 EST same day or both.
[2] One of these layers at 780 feet above hilltop.

number of occurrences of the three classes of smoky mornings for various heights at the very stable layer ($d\Theta/dz>5.5°$ F. per 1,000 feet). As shown, very smoky mornings had the highest frequency of very stable layers of air at hilltop level.

TABLE 64.—*Smoky mornings. Relation of various visibility classes to various atmospheric thermal structures*

Height of very stable layer	Valley thermal structures		
	Very stable ($d\Theta/dz>5.5°$ F./1,000 feet)	Moderately stable ($d\Theta/dz=5.5°$ F./1,000 feet)	Stable ($0<d\Theta/dz<5.5°$ F./1,000 feet)
Hilltop ($d\Theta/dz>5.5°$ F./1,000 feet)	V V V M V V	M	—
100–500 feet above hilltop ($d\Theta/dz>5.5°$ F./1,000 feet)	—	M V S	[1] S
Over 1,000 feet above hilltop ($d\Theta/dz>5.5°$ F./1,000 feet)	V	M S	SSS

V=very smoky. M=moderately smoky. S=smoky.
[1] Inversion was 780 feet above hilltop level.

Table 64, combination of tables 62 and 63, shows that the very stable layers at hilltop tended to go with very stable valley conditions to cause a very smoky morning; very stable layer between 100 and 500 feet above hilltop level and moderately stable valley conditions together tended to produce moderately smoky mornings; and very stable layers higher than 1,000 feet above hilltop level occurred with stable layers in the valley to produce only smoky mornings. However, the small quantity of data prevents this from being stated as a general rule.

The wind regime on smoky mornings was in general as follows:

a. In the valley floor, northerly flow at an average speed of 2.5 miles per hour.

b. At mid-valley height, flow more often from south and average speed from all directions of 1.5 miles per hour. There was a high percentage of calms.

c. At hilltop, velocity averaged 2.8 miles per hour from all directions but was more often southerly than northerly.

Figure 68 shows the typical flow pattern in vertical cross-section of the valley as determined on moderately smoky and very smoky mornings. This type of flow occurred most often when $d\Theta/dz>5.5°$ F. per 1,000 feet, rarely started before midnight, and usually ended before 0800 EST. The wind roses, figure 69, show for all the valley stations the percent frequencies of wind directions during valley conditions when $d\Theta/dz>5.5°$ F. per 1,000 feet. A high frequency of north directions is shown at station No. 3 and northwest directions at station No. 4. Station No. 2 at mid-valley height shows the flow from the north as well as some easterly down-hill drainage flow while No. 5, also at mid-valley height shows a very high frequency of south directions.

The Donora Cooperative Station, with wind indicators at mid-valley height near the river, showed a high frequency of west directions not readily explainable, fairly high frequency from the northwest explainable by the direction of the valley at that point and a next high percentage of north directions. Adding the north and northwest frequencies gives 50 percent of the time during moderately and very smoky conditions that the Cooperative Station instruments are in the lower valley flow from the north; the remainder of

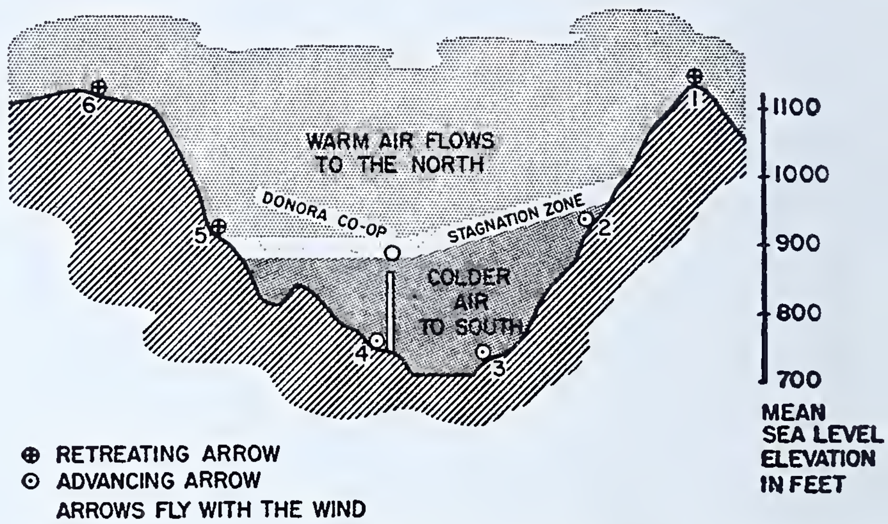


FIGURE 68.—*Average night air flow during very stable (inversion) atmospheric conditions.*

the times the lower valley flow is too shallow to affect the instrument.

The hilltop stations (Nos. 1 and 6) have high frequencies from south, southeast, and northeast with highest frequencies from south which is counter to the valley bottom northerly flow. The southerly flow can be explained by the fact that the weather system which created these smoky situations was usually a high pressure cell to the southeast of Donora. The reason for northeasterly flow at station No. 1 has not been explained by effects of topography and drainage. The up-hill wind direction from the southeast at No. 6 is possibly part of the southerly flow from high pressure cells to the south of Donora. The flow as shown by the wind rose at station No. 7, which is also at mid-valley height, may be explained thus: northeast flow prevails when deep cold air flows from the north in the valley; southeast, when the main cold air current is shallow, and drainage directly down the valley side past the station affects the wind vane; and south when a combination of drainage and south-north pressure gradient exists. The flow at station No. 8 (mid-valley height) is east when the layer of drainage air in the valley is below the level of the station and northwest when the valley has a deeper layer of cold air flowing past the station. (See fig. 67.)

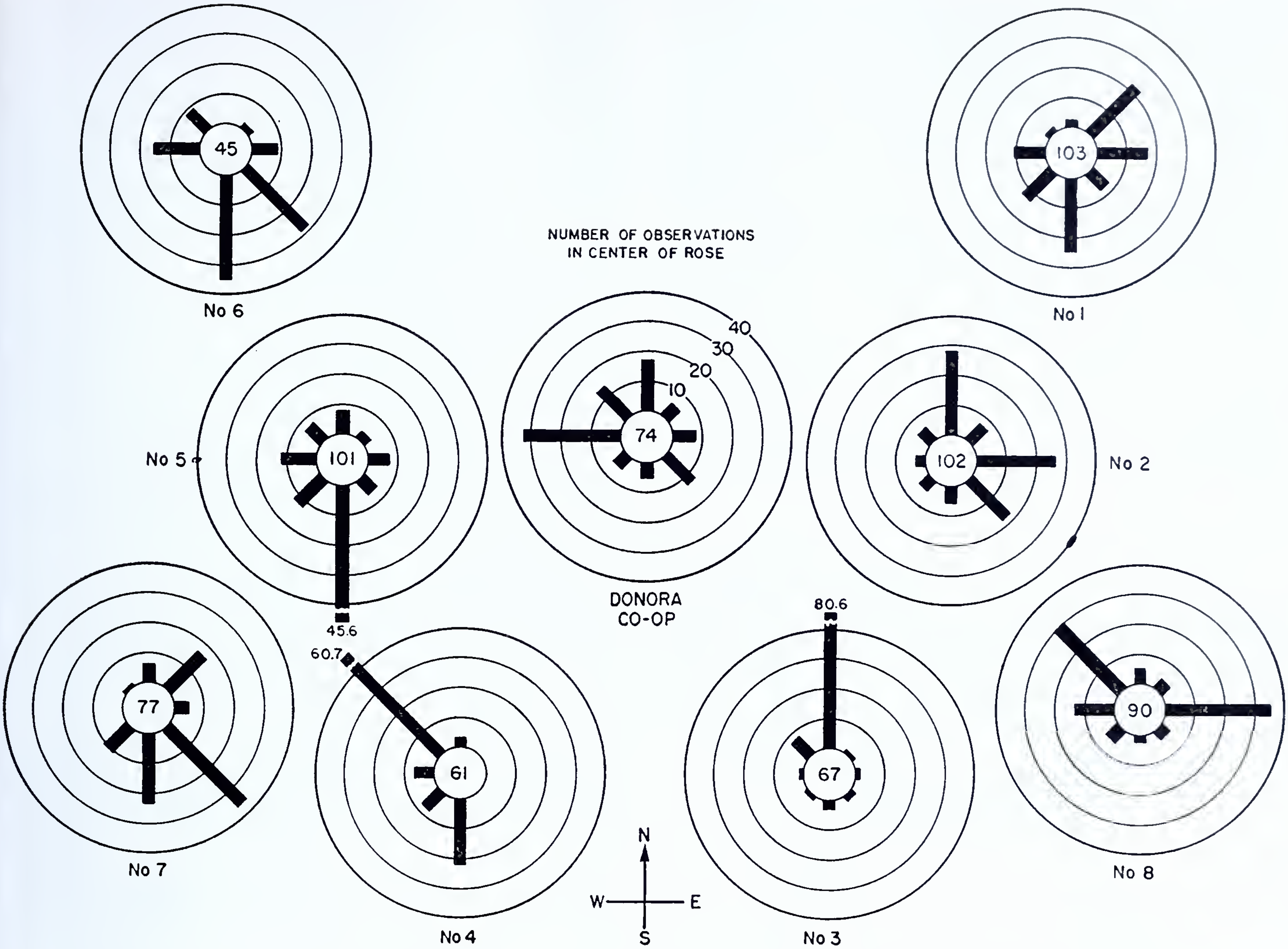


FIGURE 69.—*Percentage frequency of wind directions during very stable thermal conditions in the valley.*

During the period of the Donora investigation, visibility observations were made ordinarily during daylight hours beginning at about sunrise. On smoky mornings no stratification of the smoke in the valley could be determined since the reduction of visibility apparently was equal at all levels. Evidently turbulent mixing, operating all night, was able to produce this apparent homogeneous mixture of smoke in air. Substantiation of this may lie in the fact that even in the most stable conditions only one of the wind instruments (station No. 5) recorded any appreciable number of calms, and triple register records showed some dispersion of directions. Therefore, with reference to figure 68, figure 70 was constructed showing a shear zone at about mid-valley level with drainage air below the shear zone and warmer air above it. It is possible that combustion smokes could be carried into the shear layer and distributed north and south along the valley while turbulent motions in the cooler and warmer air layers would mix the smokes further. The evidence of continuous air movements and some direction fluctuations in the valley at night suggests a degree of turbulence. Another mechanism for diffusion of smokes throughout the valley could be the manner in which radiatively cooled air descends into a valley (*5*). Figure 71, after Geiger, shows the small individual circulations that take place as cooler air descends along a valley side. According to Geiger (*5*), this process agrees best with observation. The transport of smokes to the valley sides would allow the smokes to be circulated with the descending air currents as shown in Figure 71 and further

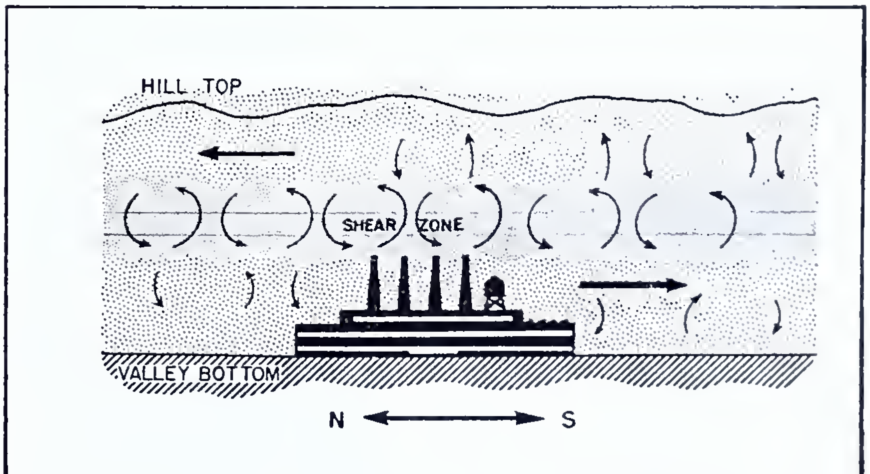


FIGURE 70.—*Manner by which wind shear may mix airborne combustion products throughout the valley.*

diffuse the smokes in the valley. Microcirculations of this small magnitude would be detected only by the direction equipment used in the investigation. A close inspection of the thermograph temperature and relative humidity traces might indirectly indicate such circulations of smoky nights. Figure 71 also shows how, according to Geiger, a very stable layer of air may form at a lower level in a valley center than on the sides. This condition was actually found to occur in the Columbia River Valley at Trail, British Columbia (*6*).

To show the prevailing surface meteorological situation at Donora during moderately smoky and very smoky mornings, pressures were averaged from 11 selected weather stations in an area bounded 10° longitude to the east of Donora and 7° longitude to the west, 5° latitude to the south and 5° latitude to the north. The isobars drawn to the average pressures indicate a high pressure area centered over Chesapeake Bay. (See fig. 72.) The isobars, aligned from southwest to northeast at Donora, place Donora in the most stable side of the high system. All the individual anticyclones which made up this composite picture were of polar origin in Canada.

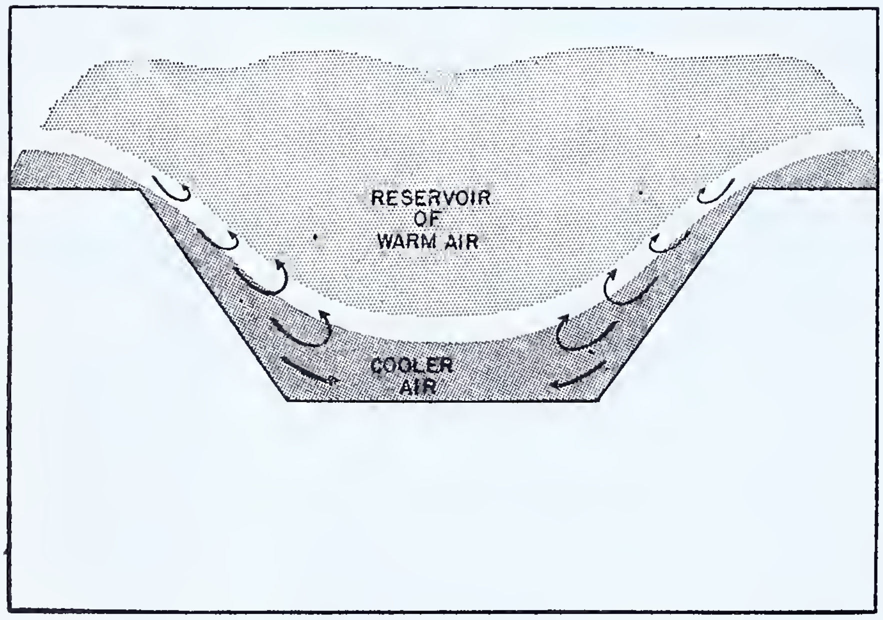


FIGURE 71.—*Manner by which radiatively cooled air descends into a valley.*

It may be concluded that the occurrence of a high pressure cell over or to the east of Donora will cause a retention of air-borne combustion products in the valley. Small-scale eddies in the nocturnal drainage flow, as shown by lack of calms on the Triple Register records, would seem to account for the apparent even distribution of smokes in the valley. This distribution was determined by visual observations only. Also in most cases of smoky mornings inversions will occur during the hours of darkness at hilltop level as well as in the valley itself. Sufficient moisture must be present to form a valley fog.

Nonsmoky, calm mornings.—The second type of weather classification studied at Donora is termed "nonsmoky, calm mornings." It was observed that some mornings were characterized by no attenuation of visibility; yet little or no wind movement in the valley was apparent by observation of smoke trails from industrial stacks. This condition occurred eleven times during the spring, 1949, investigation at Donora. A decrease of temperature with height, in the valley, was found on these mornings, and the cross section shown in figure 73 was constructed from the average temperatures at the same time of maximum lapse rate (*7*). The average maximum temperature lapse was 4° F. for the valley depth or 10.8° F. per 1,000 feet on the west slope, and 3° F. on the east slope. These lapse rates give $d\Theta/dz = -5.3°$ F. per 1,000 feet and $-2.6°$ F. per 1,000 feet, respectively, both indicating unstable layers in the valley. The difference in lapse rates for the two slopes may be explained by the fact that the west slope is warmed by the rising sun before the east slope.

Thermal structure above the hilltops showed some inconsistencies; in 4 out of 10 times a very stable layer below the 3,000-foot level occurred at the 10 a. m. observation or at both the 10 a. m. observation for the day and the 10 p. m. observation the night before. Very stable layers at hilltop occurred twice but only at 10 p. m. of the night before the day considered. However, with a steep lapse rate in the valley and a very stable layer some distance above hilltop level, smoke would rise out of the valley easily and possibly would be carried away aloft if the very stable layer were easily penetrated (*8*). Large smoke columns were in fact observed several times rising straight up to one and one-half to two times hilltop level and then being carried away horizontally to the east while no smoke accumulated in the valley. In the six remaining instances, normal stability existed aloft both at 10 p. m. of the night before and at 10 a. m. of the day considered.

Valley winds were investigated only for the purpose of detecting cross valley thermal currents caused by unequal heating of the valley walls at different times of the day. Table 65 shows frequencies of each hourly prevailing direction summed hour by hour from 0700 to 1800 EST for all stations for nonsmoky, calm days. For example, at 0700 EST only 2 hours of north directions were accumulated on all the days included and at all the stations, while at 1400 EST, 24 hours of accumulated west directions were recorded at all stations. The columns for sums of east and west components show that the westerly components increased almost steadily from 0700 to 1500 EST then dropped off at 1700 and 1800 EST; an inspection of the west and northwest columns shows the maximum frequency to be northwest from 0700 to 1000 EST, and west after 1000 until 1800 EST at which time it

TABLE 65.—*Sums of hours of wind directions from all stations for nonsmoky, calm days*

Time (EST)	Sums of hours								Sum E	Sum W
	N	NE	E	SE	S	SW	W	NW		
0700	2	3	7	8	7	2	13	22	18	37
0800	0	2	4	9	9	2	16	17	15	35
0900	2	2	0	8	7	7	15	18	10	40
1000	0	2	2	5	6	12	13	20	9	45
1100	0	1	4	7	7	15	16	15	12	46
1200	1	2	3	8	3	14	18	19	13	51
1300	0	0	1	8	3	18	19	17	9	54
1400	0	0	0	7	4	17	24	16	7	57
1500	0	0	0	5	3	14	30	16	5	60
1600	0	2	0	6	11	11	29	12	8	52
1700	1	5	5	6	5	8	23	15	16	46
1800	2	10	7	4	4	7	17	18	21	42

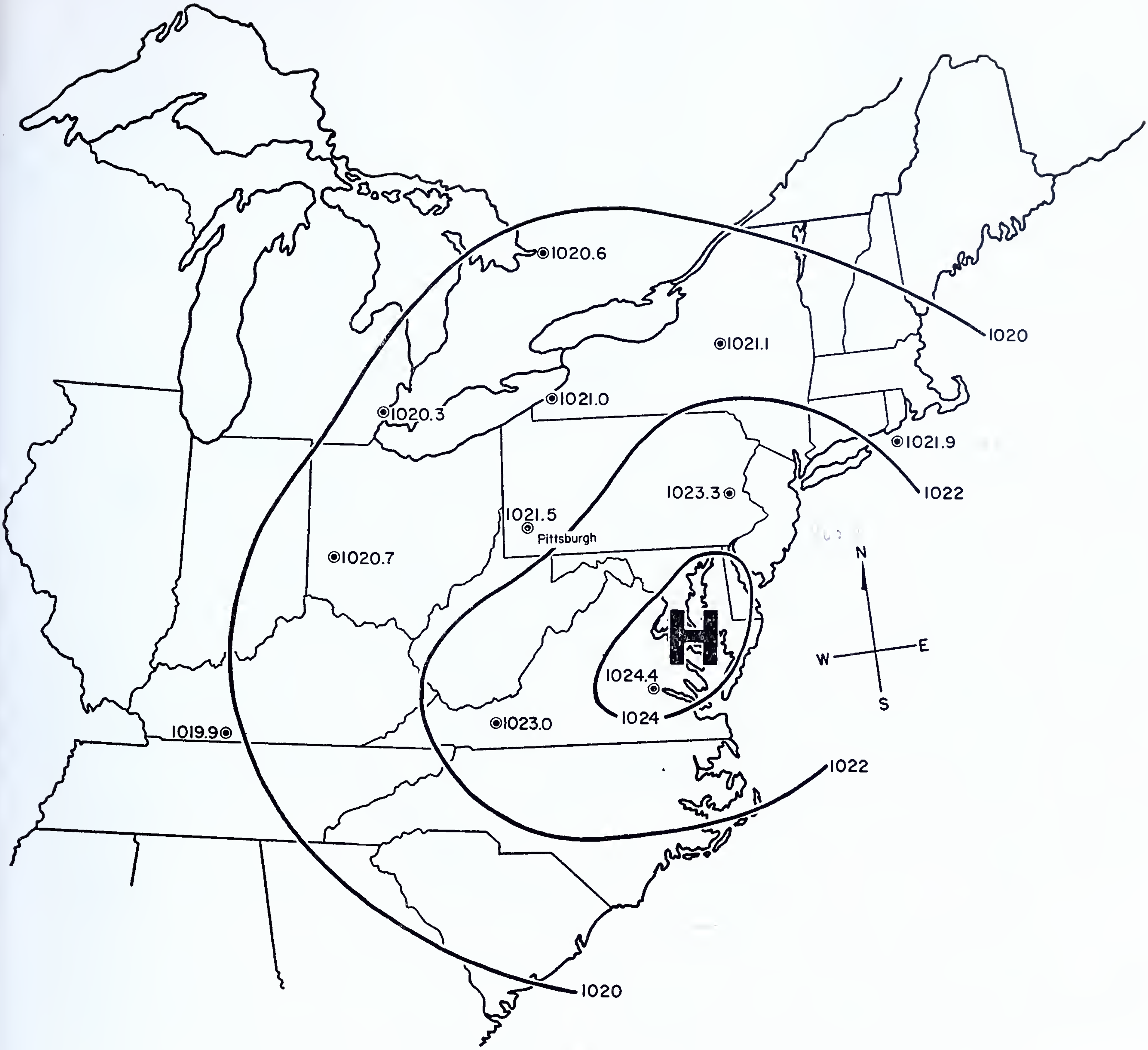


FIGURE 72.—*Average pressure distribution for all very stable nights.*

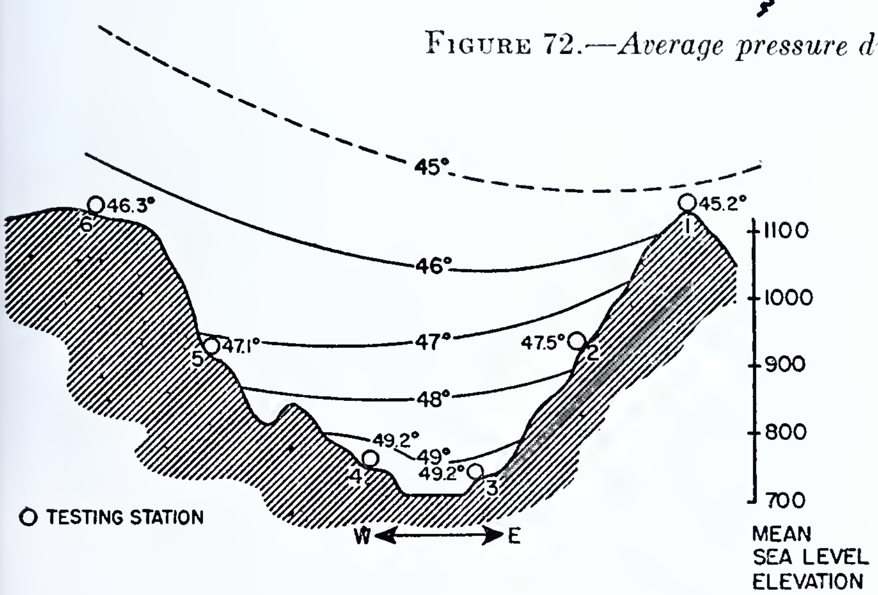


FIGURE 73.—*Average thermal structure across valley on non-smoky calm days. At time of maximum lapse rate.*

returned to northwest. Both of these changes might be explained by the fact that the average directions of the prevailing pressure gradient for these days was from the northwest. So, early in the day, the air drifted from the northwest until the westerly component, caused by gradually increased heating of the east wall of the valley by the sun, overcame the prevailing pressure gradient. The relatively high frequency of east directions in the early morning may be explained by the early heating of the west wall of the valley when the sun first rises. (See fig. 73.) This warmer air close to the west hillside rises and cooler air on the east wall descends to replace it. This process produces easterly direction components in the early half of the morning. One may conclude that the diurnal effect of cross valley flow components caused by unequal heating of alternate sides of

FIGURE 74.—*Average surface pressure distribution for nonsmoky calm days.*

a valley wall functions in the valley at Donora, Pa., on calm or near calm days.

The average surface chart for nonsmoky, calm days is shown in figure 74. Pressures at selected stations were averaged for all the days of this category. Isobars were drawn to obtain the average surface weather type. This average type has a cold front over 150 miles south of Donora placing Donora in relatively unstable post cold frontal air. This air of polar continental origin is heated from below as it moves southward, and its stability decreases (*9*). Thus, this unstable air mass furnishes enough turbulence to dissipate smokes without appreciable wind.

Windy periods.—The third type of weather classification at Donora is termed "windy periods." These periods are defined as periods lasting at least 8 hours, having average hourly velocities of over 10 miles per hour and reaching a peak average hourly velocity of 15 miles per hour at station No. 1. It was not considered necessary to investigate the thermal structure of the valley since the lapse rate in the lower layers in windy weather is known (*10*) to be near the adiabatic rate of 5.5° F. per 1,000 feet ($d\Theta/dz=0$). Vertical mixing of air parcels proceeds easily under this neutral stability condition. Because of the higher average wind velocity and smaller stability in windy periods no smoke collected in the valley, but differences in the rate of diffusion of smoke trails were noted.

The frequency distribution of wind directions in these windy periods is shown in figure 75. Of interest are the maximum frequencies of west directions at both hilltop stations (Nos. 1 and 6). The secondary maximum of northwest

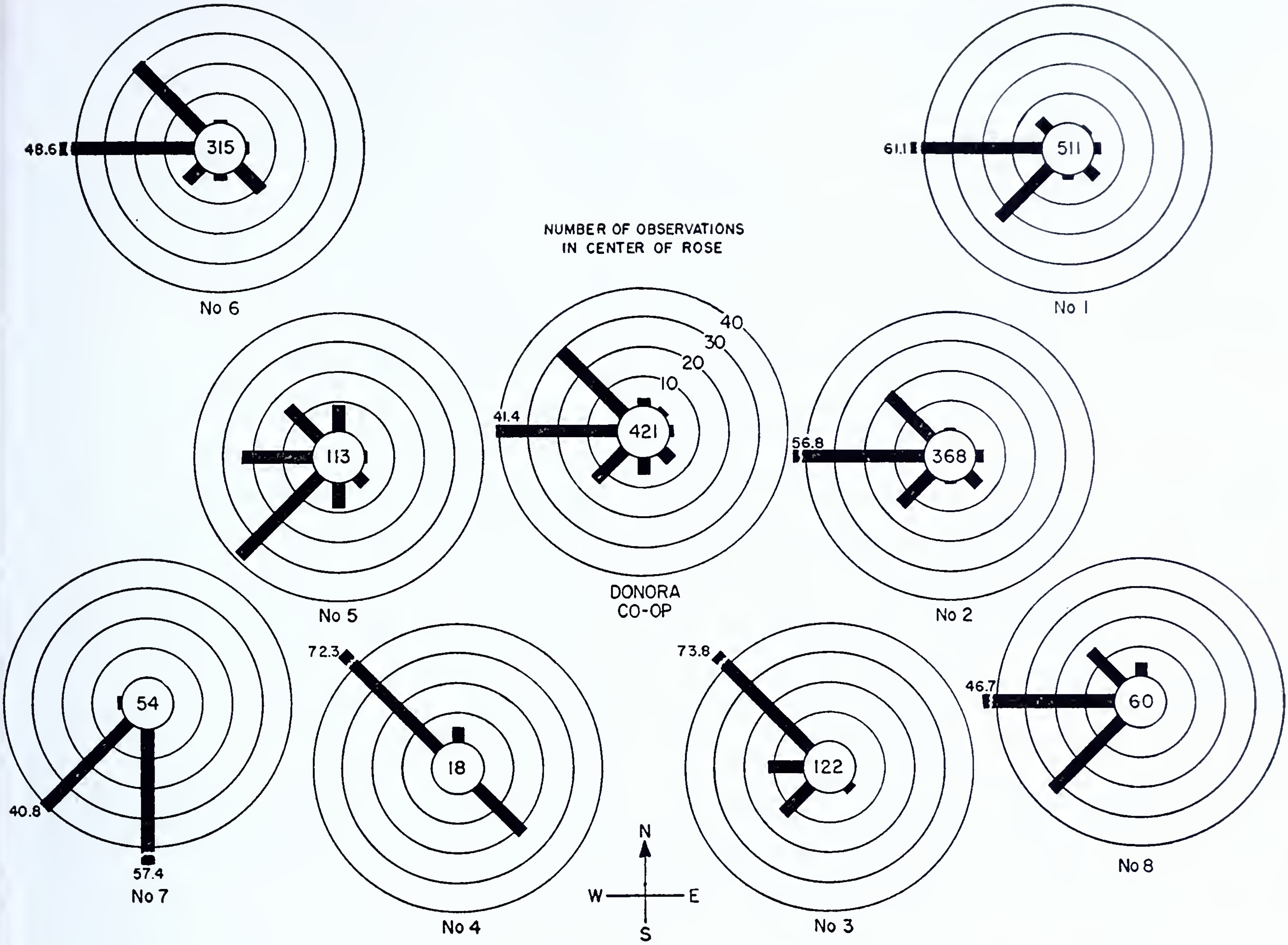


FIGURE 75.—*Percentage frequency of wind directions for windy periods.*

directions at station No. 6 may be explained by the higher peak to the west and lesser elevations to the northwest. Station No. 2 shows no turning of the wind 55 percent of the time, but the secondary maximum frequency of directions from the northwest is consistent with the orientation of the valley at that point. (See fig. 67.) The primary maximum of southwest directions at station No. 5 may be related to the northeast-southwest ridge immediately to the west of the station. The primary maximum of northwest winds at station No. 3 is consistent with the direction of the valley at that point. The secondary maximum of southwest is not easily explained. Station No. 4 is situated in a rather narrow channel alined NNW-SSE between a high bank to the west and tall industrial sheds to the east. Therefore, 95 percent of its winds are from northwest or southeast; southeast directions account for only 21 percent of the directions. The Donora Cooperative Station wind instruments situated at almost midvalley both horizontally and vertically show a high percentage of west directions and a secondary maximum from the northwest.

At station No. 7 the high maximum frequency of directions from the south is not easily explained, but the secondary maximum from the southwest conforms to the valley orientation.

The high frequency of west winds at station No. 8 shows the persistence of west winds from the long straight E-W portion of the valley to the west of the station.

The wind roses of figure 75 show in a general way the wind direction pattern for windy periods as defined above. Note the very low percentages of north, east, and south directions. To show more accurately the turning of the wind in the valley, wind directions in the valley were inspected when the direction at hilltop station No. 1 was from a specified direction. These results are given in table 66.

When the hilltop station No. 1 is indicating a west wind, the other hilltop station No. 6 has its highest frequency of directions from the west. Station No. 2 has its highest frequency from the west as does No. 5 on the same level as No. 2, but on the opposite side of the valley. Station No. 3 in the valley floor has its highest frequency from the northwest which is the approximate orientation of the valley there. Station 4 has frequencies almost evenly divided between west and northwest which is apparently contradictory to the wind rose frequencies for windy periods in figure 75. Station No.

TABLE 66.—*Distribution of the frequency of hourly prevailing wind directions at the various stations, for specified wind direction during "windy periods" at Hilltop Station No. 1*

Wind direction	Station No.								
	1	2	3	4	5	6	7	8	[1] D
	West wind at Station No. 1								
West	115	80	21	33	54	56	24	35	58
Northwest	----	17	41	35	24	10	4	34	25
Southwest	----	0	0	0	13	0	68	0	0
Total	115	97	62	68	91	66	96	69	83
	Southwest wind at Station No. 1								
West	----	4	2	0	0	0	0	12	2
Northwest	----	0	0	0	0	0	0	0	0
Southwest	28	17	9	9	12	1	6	0	12
South	----	0	1	0	0	4	10	0	2
Total	28	21	12	9	12	5	16	12	16
	Northwest wind at Station No. 1								
Northwest	2	2	1	2	0	1	1	1	2
West	----	0	0	0	0	0	1	0	0
Total	2	2	1	2	0	1	2	1	2
	Southeast wind at Station No. 1								
Southeast	10	10	2	4	3	10	[2]	[2]	2
South	----	0	0	0	2	0	0	0	8
Total	10	10	2	4	5	10	[2]	[2]	10
	South wind at Station No. 1								
South	6	3	2	2	3	0	[2]	[2]	6
Southeast	----	3	0	1	0	6	[2]	[2]	0
Total	6	6	2	3	3	6	[2]	[2]	6
	North wind at Station No. 1								
North	1	0	0	0	0	0	0	0	0
West	----	1	0	0	1	0	0	0	0
Southwest	----	0	0	0	0	0	1	1	0
Total	1	1	0	0	1	0	1	1	0

[1] Donora Cooperative.
[2] Missing data.

3 which is more nearly free of obstructions than No. 4 shows the highest percentage of turning; however, just to the east of No. 3 is a cliff about 125 feet high which may accentuate the turning of the wind. At station No. 7, the wind shows directions from the southwest about three times as often as it shows west directions; the valley is oriented northeast-southwest there. Station No. 8 has frequencies evenly divided between west and northwest; at that location, the northwest-southeast orientation of the valley may account for the turning of the winds. The Donora Cooperative Station shows twice as many west as northwest direction frequencies; the valley is oriented north-northwest to south-southeast at that location. From the frequencies for stations Nos. 7 and 8, it might be concluded that with strong west winds at hilltop level a degree of horizontal convergence occurs in the vicinity of Webster. This effect was shown previously in figure 65, wind roses for entire period and all winds.

When the hilltop wind at station No. 1 is from the southwest, station No. 6 on the opposite hilltop has its highest direction frequency from the south; paucity of observations could account for the distribution. Stations Nos. 2, 3, 4, and 5 have their highest number of directions from the southwest. The southwest direction at station No. 5 is consistent with the station location to the east of a northeast-southwest ridge.

At station No. 7, winds become predominately from the south with a minor frequency from the southwest; the valley is aligned southwest-northeast at that point, but the cause of the high frequency of south winds is obscure. Station No. 8 has winds only from the west. The Donora Cooperative Station shows by far its highest direction frequency to be from the southwest with a slight tendency for winds from the south, a direction nearer to the valley direction than is southwest.

When the wind at hilltop station No. 1 is from the northwest, the wind at all stations in northwest except at No. 7 where frequencies are equally divided between northwest and west. However, the number of observations for this situation and those when No. 1 is from the south and from the north are so small that results are not decisive.

When the wind at station No. 1 is from the southeast, the direction at station No. 6 also is southeast. Station No. 2 direction also remains southeast, consistent with the valley direction. The Donora Cooperative Station records a predominately south wind.

The wind speeds of the valley during windy periods were examined. All of the periods except one had prevailing westerly components at station No. 1. Fortunately for comparison purposes the one exception was prevailing southeast. Figure 76 shows the results. For westerly component hilltop winds, the only level that shows comparable average speeds are the two hilltop stations; oddly enough the downstream station shows higher average speeds. Station No. 4, the most sheltered of the group, shows the lowest average speed. Also stations Nos. 4, 5, and 6 as a group are lower in average speed than Nos. 1, 2, and 3; the former are in the lee slope of the valley while the latter three are on the windward slope for westerly winds. The river bend stations (Nos. 7 and 8) have more nearly the same average speeds although farther apart in geographical location than any other two stations compared.

During the period of southeast prevailing winds at station No. 1, the lee slope and windward slope effect is reversed with stations Nos. 1, 2, and 3 having lower average speeds than stations Nos. 4 and 6 (No. 5 missing) as a group. Also, the Donora Cooperative Station actually shows a higher speed than station No. 1 and almost as high as No. 6, the highest for the southeast wind type. It is about 150 feet above the surface and, therefore, has less frictional effect than Nos. 1 and 6. Station No. 4 and the Donora Cooperative Station show the greatest increase of speed over the west-

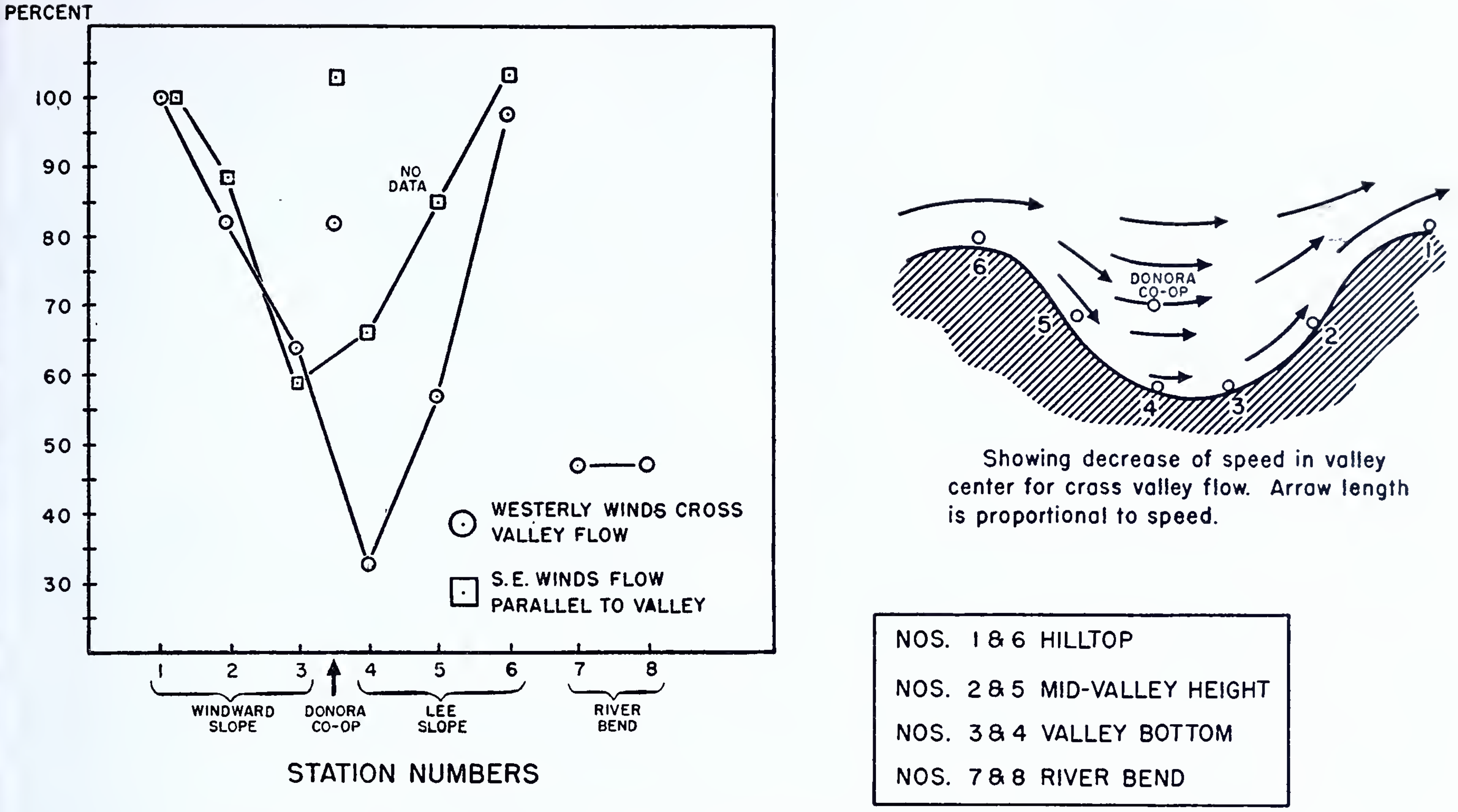


FIGURE 76.—*Windy period speed structure for flow parallel to the valley and cross-valley flow.*

erly wind type. However, it must be remembered that only one windy period with a prevailing southeast hilltop wind was recorded. Several periods averaged together might change the pattern.

The following conclusions are drawn for the "windy periods":

1. In spite of the horseshoe shaped configuration of the valley at Donora, the valley tends to turn the prevailing wind parallel to the valley side.

2. Cross valley winds are decreased in velocity more on the lee slope than on the windward slope.

3. Cross valley winds are retarded in the valley to a greater extent than winds parallel to the valley.

The decrease of wind velocity in the valley when the hilltop prevailing velocity is cross valley agrees with the Bernoulli theorem which, in general, states that velocity in a fluid stream will decrease if the cross-section area is increased.

Synoptic type situations were determined for windy periods at Donora, as before, by averaging pressure at selected stations during windy periods. Figure 77 shows the composite synoptic situation. It has a trough of low pressure through Donora going north-northeast to the main low over Maine.

During the period of spring 1949 at Donora, windy periods were characterized by proximity of cyclonic weather with cyclone centers to the west or northwest and to the east or northeast of Donora. Frontal passages were observed at Donora during which no appreciable wind velocity difference was noted indicating that the cyclone center passed to the north of Donora sufficiently far to keep the low-velocity center from affecting Donora.

THE DONORA SMOG EPISODE OF LATE OCTOBER 1948

Examined in light of the preceding description of the micrometeorology of the Donora area, the Donora smog episode of late October 1948, is found to be an extreme case of the "smoky morning" class of valley weather. This section of the report which is based partially on a study by Fletcher (*11*), relates the meteorological history of the period 25 to 31 October 1948, in the vicinity of Donora, Pa. This period was a case in which the morning fog and smoke did not break up with diurnal heating but remained for 4 days. It was not meteorologically unique for Donora; Willett (*12*) indicates that in 1923 and 1938 similar general meteorological conditions existed, both times in October, although records for weather in the valley at Donora are not available. But the episode was unique in that 17 people died within 14 hours in and around Donora on October 30, allegedly as a result of the high concentration of airborne combustion waste products.

The basic requirement for existence of dangerous air-pollution potentialities, concentration of numerous and active sources of smoke and gases resulting from combustion, is met at Donora, which lies near the center of a heavily industrialized region. That the topography is favorable for local concentrations of smoke and gases is apparent from examination of figure 78 which shows the approximate course of the 1,000-foot elevation contour in southwestern Pennsylvania. It can be seen that if the bulk of the pollution is emitted at an elevation of, say, less than 1,000 feet, and if forces are active in preventing the pollution from spreading upward,

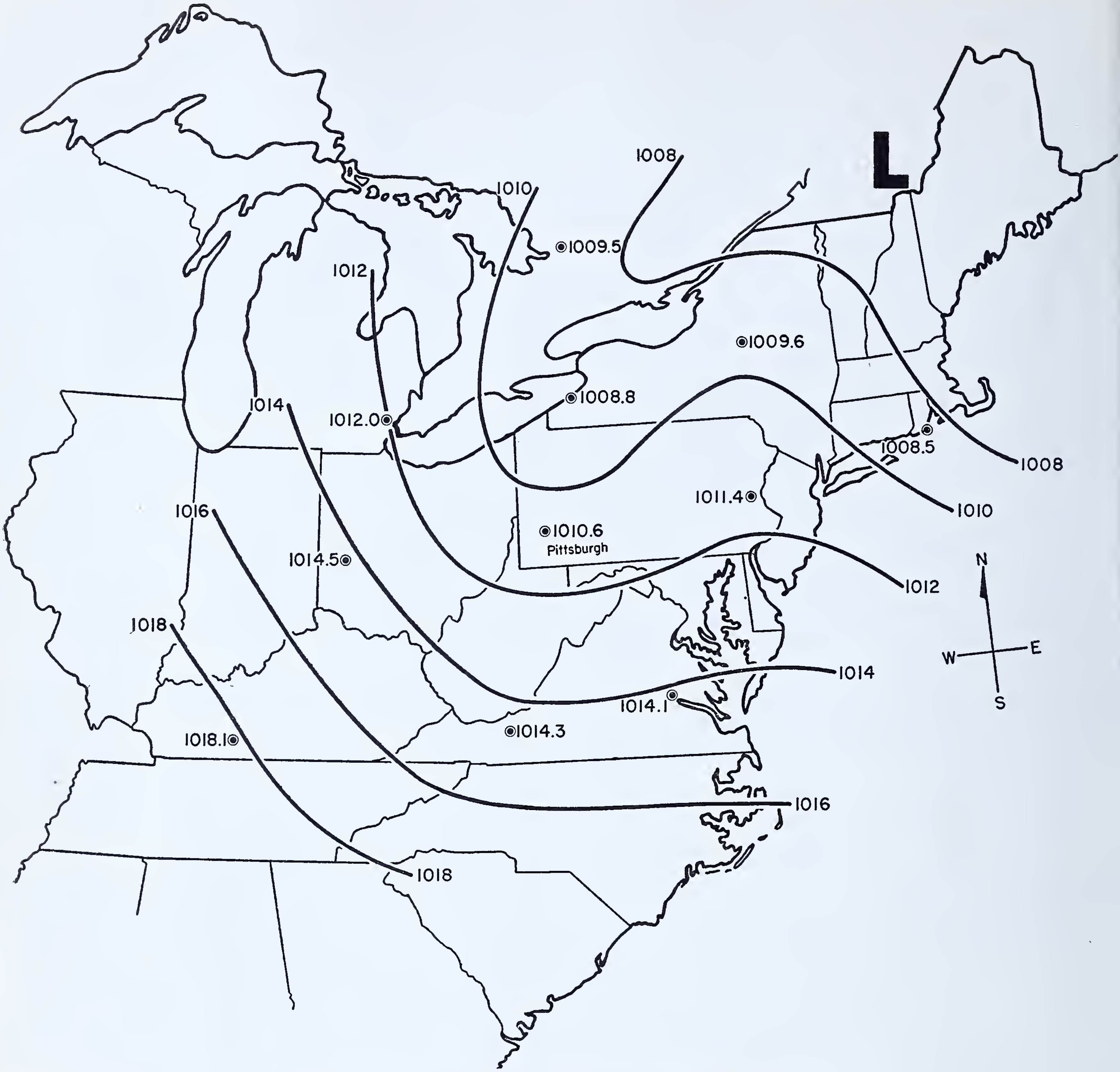
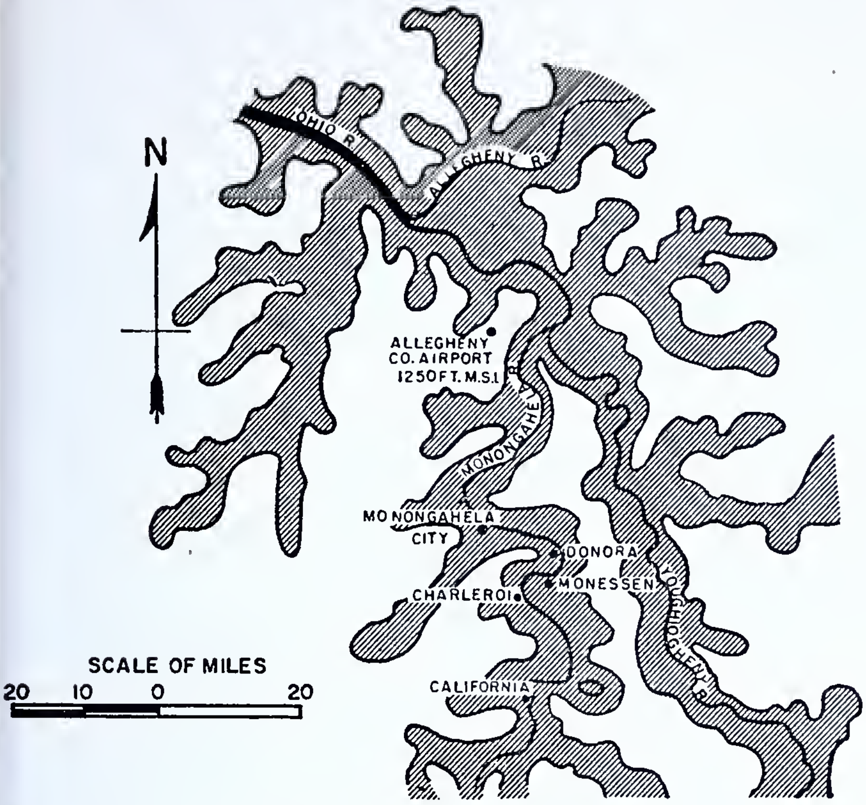


FIGURE 77.—*Average pressure distribution for windy periods.*

the space in which the pollution is free to drift will be relatively small. In fact, the river valley and its tributary valleys can be compared, in such a case, with a tunnel having numerous "blind-alley" tunnels as appendages. If the wind circulation happens to be very weak within the tunnel system, the constant and great emission of pollution will produce a steady accumulation of smoke and gases within the system.

On October 26, 1948, an eastern-seaboard storm had receded and was being replaced by a polar anticyclone advancing from the west. During the day the HIGH became established over western Pennsylvania. It remained in approximately the same position for 5 days, during which period the skies were nearly cloudless and what low-level wind circulation existed produced a very weak, but fairly steady, drift southeastward from the Pittsburgh area toward Donora. Due to the clear skies, fogs formed and persisted in the lowlands. As a matter of fact, considerable areas of fog were to be found over most of Pennsylvania and in parts of neighboring States. The lack of turbulence caused by lack of wind and lack of valley-bottom daytime heating (the latter in turn caused by the high reflectivity of the fog layer) prevented a breaking up of the fog and smoke layer near Donora and kept daily maximum temperatures at Donora lower than the maximum temperature at the Pittsburgh airport. The man-



THE PITTSBURGH DONORA AREA

FIGURE 78.—*Area below the 1,000-foot contour in the vicinity of Donora and Pittsburgh, Pa., is shown by shading.*

ner in which a fog layer in a valley restricts valley-bottom daytime heating and strengthens the stability in the valley is shown in figure 79. The high reflectivity of a fog layer top is illustrated in figure 79 (a); the latest experimental values for the reflective power, or albedo, of fog layers 500 feet thick average 50 percent and sometimes are as high as 85 percent (*13, 14*). For purposes of comparison the average land surface has an albedo of 10 percent and water surfaces between four and five percent. At night the fog top radiates as a black body which cools the air in the radiating layer; this cooled air sinks toward the valley floor decreasing the temperature there (*15*). Figure 79 (b) illustrates the latter process.

On October 31, a weak frontal zone slowly approaching from the west moved into the area, changed the wind to a southerly one with increased speeds, and brought cloudiness, rain, and an end to the disastrous combination of circumstances at Donora. The sequence of United States Weather Bureau map for the period October 26–31 is illustrated in figure 80.

Aerological soundings were taken at 1000 and 2200 EST, at the nearby Pittsburgh Weather Bureau Airport Station, located at an elevation of about 1,250 feet. Prior to and following the critical period, the lowest layer of air was characterized by a low degree of stability. By the evening of the 25th increasing stability was apparent, and late on the 26th a very stable surface layer had formed. On the morning of the 27th, although considerable stability was present in the lowest layers, the base of the very stable layer was about 500 feet above the ground. From the evening of the 27th through the evening of the 31st a very stable layer at the surface was measured on every sounding. Figure 81

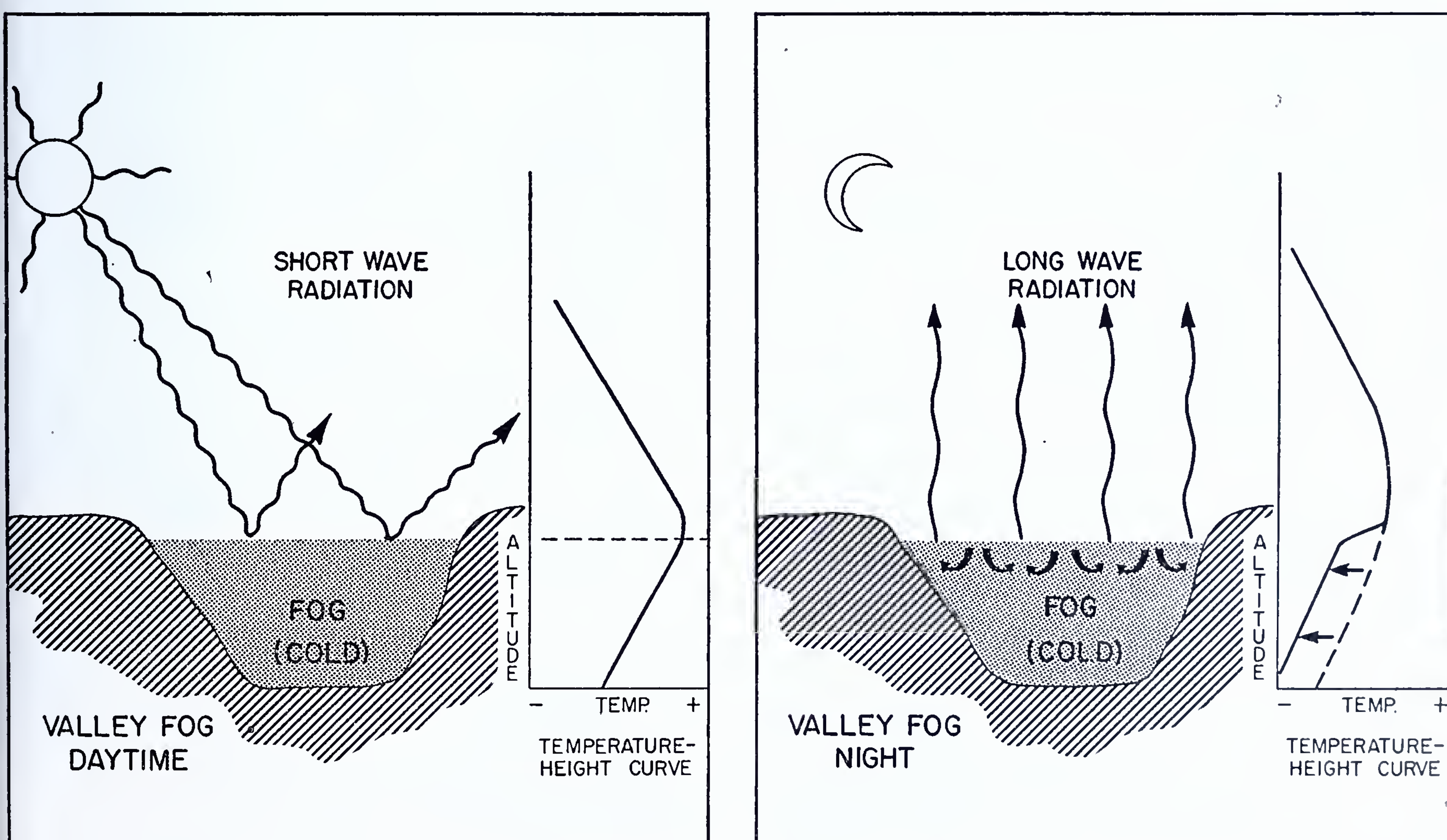


FIGURE 79 (a–b).—*Function of fog in maintaining valley stability.*

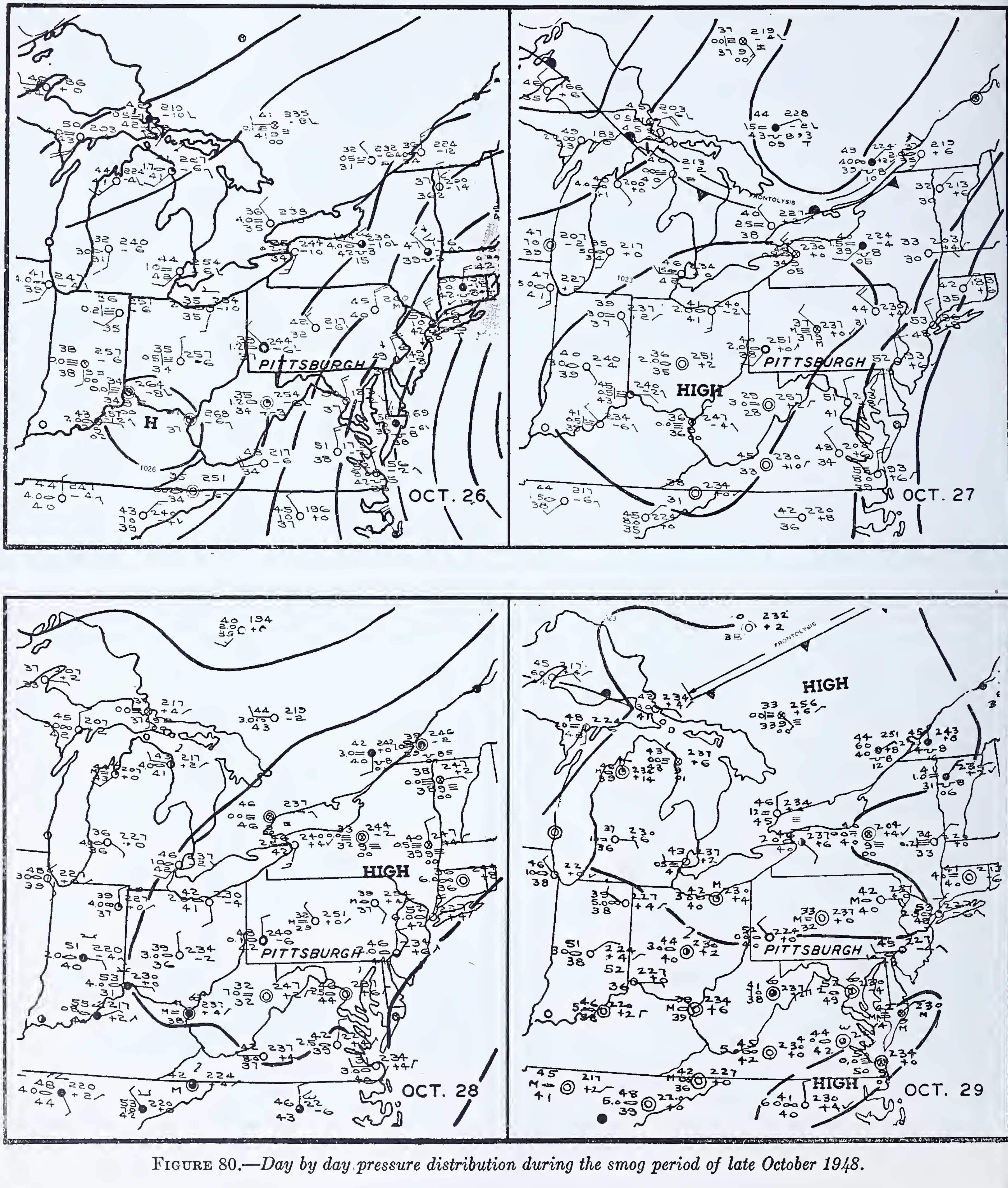


FIGURE 80.—*Day by day pressure distribution during the smog period of late October 1948.*

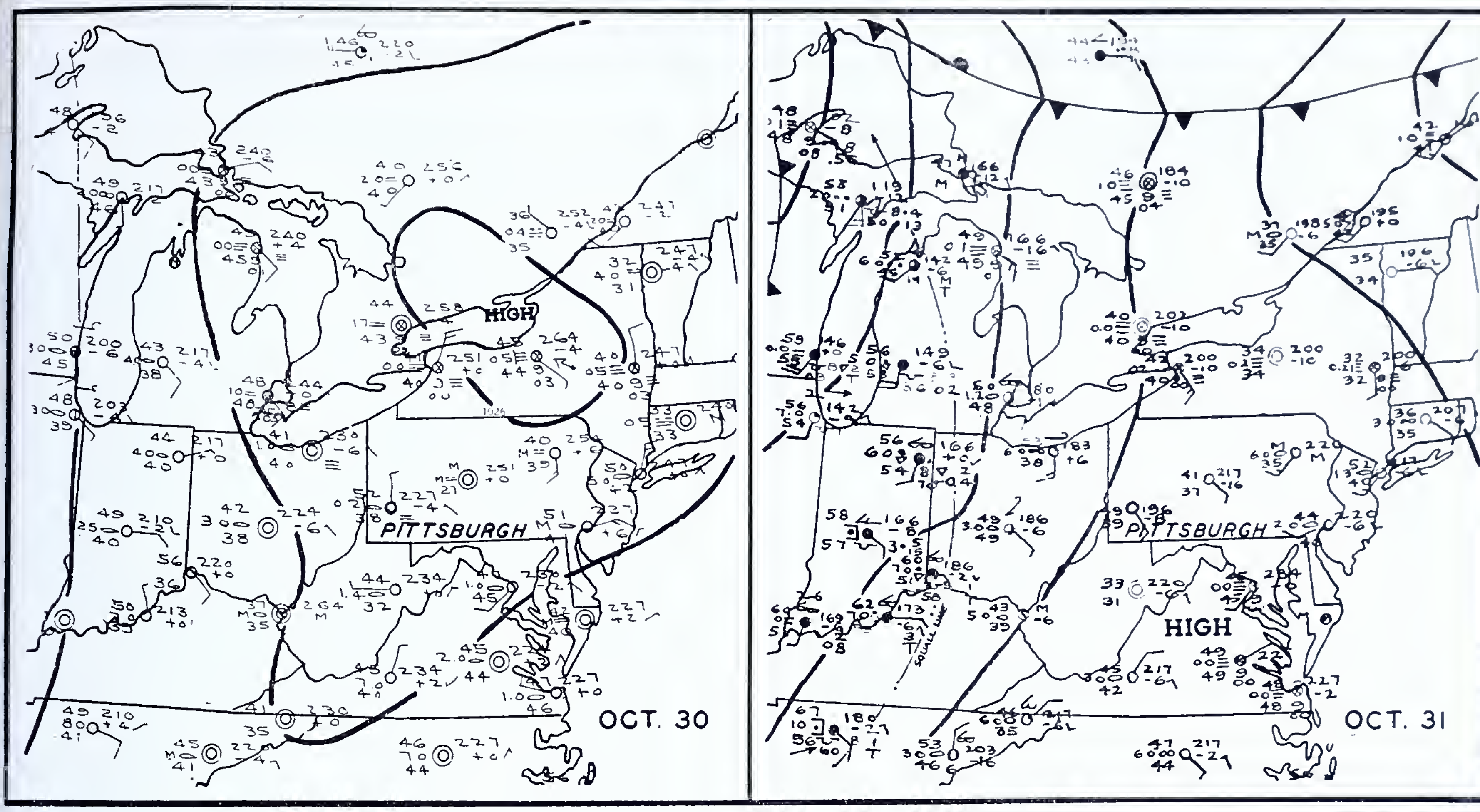


FIGURE 80.—*Day by day pressure distribution during the smog period of late October 1948*—Continued.

shows the progressive "clamping down" of the very stable layers in the vicinity of Donora.

From records of the United States Weather Bureau Cooperative Observer Station maintained at Donora are available the daily maximum, minimum, and noon temperatures. In comparison with similar measurements made at the Pittsburgh airport, the Donora values provide a striking illustration of the pronounced stability which dominated the Monongahela Valley during the critical period. Potential temperature ascendant, a measure of the force which suppresses vertical motion of the air, was computed for the noon readings of the two stations for the months of October and November, 1948. The potential temperature ascendants were obtained by subtracting the Donora temperature from those at the airport, converting to ΔT/1,000 feet, adding the result to the adiabatic lapse rate. These values, in degrees Fahrenheit per thousand feet, are shown in table 67. Positive values indicate stability, negative values indicate instability.

Immediately apparent is the great stability which prevailed during the period when severe atmospheric pollution existed, October 26–30. Following a "peak" of stability on the 27th and a slight abatement on the 28th, greatest stability existed on the 29th and 30th. Seventeen of the twenty Donora deaths occurred on the 30th. With the approach of the frontal zone on the 31st, stability returned to normal. Similar measurements of stability were computed for the Donora and Pittsburgh maximum and minimum temperature for the period October 25–31. Presented in figures 82 (a) and 82 (b) respectively, these values suggest that each noon stability was fairly representative of the stability for the day. The stability-sequence of the lowest layer of air above the Pittsburgh airport, from October 24 through November 1, is shown in figures 82 (c) and 82 (d). Here, the lapse rates of the lowest layer were determined from the surface

TABLE 67.—*Stability as measured by noon potential temperature differences between Donora and Pittsburgh Airport, degrees F. per 1,000 feet*

Date (1948)	Stability $\Delta\theta/\Delta z$	Date (1948)	Stability $\Delta\theta/\Delta z$
Oct. 1	3. 3	Nov. 1	1. 3
Oct. 2	7. 4	Nov. 2	−2. 8
Oct. 3	−2. 8	Nov. 3	−2. 8
Oct. 4	−4. 8	Nov. 4	3. 3
Oct. 5	−2. 8	Nov. 5	1. 3
Oct. 6	−2. 8	Nov. 6	−. 8
Oct. 7	23. 7	Nov. 7	−2. 8
Oct. 8	−2. 8	Nov. 8	3. 3
Oct. 9	3. 3	Nov. 9	1. 3
Oct. 10	−6. 9	Nov. 10	−8. 9
Oct. 11	−2. 8	Nov. 11	−. 8
Oct. 12	1. 3	Nov. 12	−2. 8
Oct. 13	−. 8	Nov. 13	7. 4
Oct. 14	3. 3	Nov. 14	3. 3
Oct. 15	−4. 8	Nov. 15	−. 8
Oct. 16	5. 4	Nov. 16	3. 3
Oct. 17	−2. 8	Nov. 17	1. 3
Oct. 18	−. 8	Nov. 18	3. 3
Oct. 19	5. 4	Nov. 19	3. 3
Oct. 20	5. 4	Nov. 20	−. 8
Oct. 21	−. 8	Nov. 21	5. 4
Oct. 22	1. 3	Nov. 22	1. 3
Oct. 23	−. 8	Nov. 23	−4. 8
Oct. 24	7. 4	Nov. 24	9. 5
Oct. 25	1. 3	Nov. 25	5. 4
Oct. 26	13. 6	Nov. 26	−4. 8
Oct. 27	21. 7	Nov. 27	1. 3
Oct. 28	19. 7	Nov. 28	1. 3
Oct. 29	38. 0	Nov. 29	1. 3
Oct. 30	34. 0	Nov. 30	−. 8
Oct. 31	7. 4		

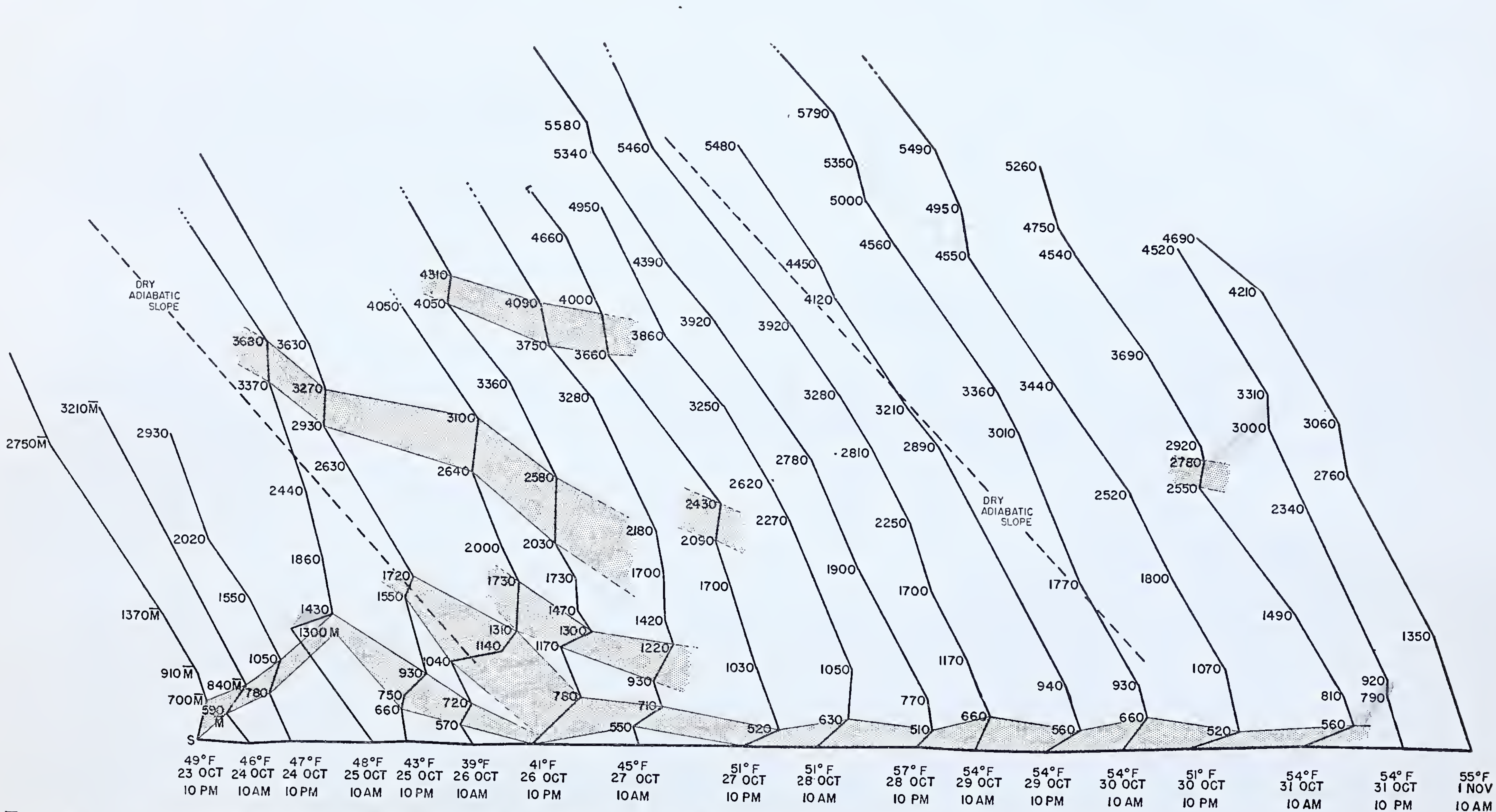


FIGURE 81.—*Twice daily aerological soundings taken at Allegheny County (Pittsburgh) Airport Weather Station. Figures along lapse curves are mean sea level elevations in meters of significant levels. Temperature for each curve decreases to the left. Very stable layers (inversions) are shaded.*

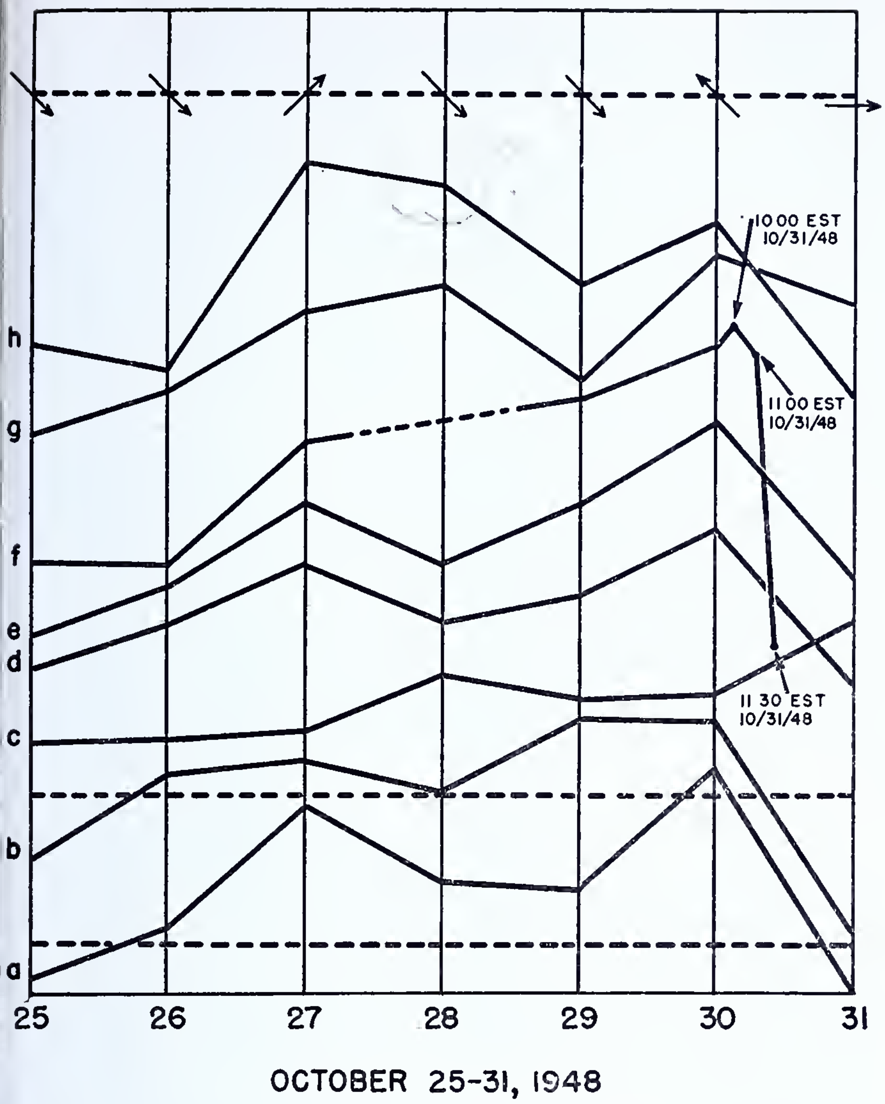


FIGURE 82.—*Comparison of weather parameters at Donora and Pittsburgh airport for October 25–31, 1948. Points on graph are daily average values and lines merely connect the points.* (See table 68.)

and first significant level of each twice daily aerological sounding, and the stability was computed as before. Behavior of the stability above the airport seems to have been quite similar to that within the river valley.

With regard to the atmospheric-pollution problem, vertical stratification of temperature is significant largely because of its ability to indicate the degree to which vertical turbulent components of air movement are suppressed. With constant stability, however, a stronger wind moving over a ground surface will produce greater eddy components, hence will act more strongly to disperse pollution through vertical spreading. In addition to its implications as regards turbulence, the average wind is of prime importance as an agent which spreads pollution horizontally. It should be expected, therefore, that wind speed and pollution concentration are inversely related. Figure 82 (e) was constructed from the hourly surface wind data, October 25 through November 1, recorded at the airport, and consists of a running graph of the daily harmonic average wind speed, in miles per hour. These values were computed by averaging the reciprocals [2] of the recorded wind for each hour of each day (classed as 1 mile per hour whenever a calm was reported). Correspondence of the wind-parameter graph is remarkable. The wind parameter was high on the 27th, weakened on the 28th, and then rose steadily to its maximum value on the 30th, the most disastrous day of the smog situation. (See fig. 82, a graphical illustration of table 68.) As the winds picked up in strength with the approach of the frontal zone, the wind parameter dropped rapidly on the 31st. While it is true that a large percentage of the variation in wind speed must have been due to variation in stability, the two factors being intimately interrlated, it is probable that a significant portion of the pollution-concentration variation was due to variation in wind speed alone.

For given values of surface wind and stability, a stronger value of vertical wind shear in the pollution layer will bring about a greater vertical interchange of the air parcels containing pollution and, accordingly, lower values of pollution concentration. Wind-shear data, in miles per hour per thousand feet, were obtained from the surface and 2,000-

[2] Reciprocals are used to make other weather parameters rise as stability factor rises.

TABLE 68.—*Daily values of stability parameters.* [*Figure 82 (a–h) is determined from these values*]

Date (1948)	(a) [1] Stability (maximum temperature)	(b) Stability (minimum temperature)	(c) Stability (1000 EST aerological sounding)	(d) Stability (2200 EST aerological sounding)	(e) Pittsburgh hourly surface winds	(f) Pittsburgh wind shear	(g) Pittsburgh visibilities	(h) Smoke top heights
Oct. 23				6.8				
Oct. 24			−0.4	2.4				
Oct. 25	−6.9	−8.9	.6	4.2	0.13	0.38	0.29	0.33 (2000 EST).
Oct. 26	1.3	3.3	1.6	11.6	.20	.32	.59	0.33 (1900 EST).
Oct. 27	19.7	5.4	3.7	19.3	.32	.88	1.13	0.50 (0700 EST).
Oct. 28	9.5	1.3	11.8	11.8	.24	.83	1.34	
Oct. 29	9.5	11.5	8.3	15.5	.33	.56	.67	0.56 (0900 EST).
Oct. 30	25.8	11.5	9.9	25.6	.44	.75	1.51	0.63 (1100 EST).
Oct. 31	−4.8	−17.1	20.8	3.5	.13	.28	1.16	0.65 (1000 EST). 0.61 (1100 EST). 0.20 (1130 EST).
Nov. 1			.5		.26		1.02	

[1] Explanation of values to construct graphs (a)-(h) in fig. 82:
(a) Stability as measured by maximum daily temperatures, Donora and Pittsburgh Airport, $d\theta/dz$.
(b) Stability as measured by minimum daily temperatures, Donora and Pittsburgh Airport, $d\theta/dz$.
(c) Stability as measured by 1000 EST aerological sounding at Pittsburgh Airport, $d\theta/dz$.
(d) Stability as measured by 2200 EST aerological sounding at Pittsburgh Airport, $d\theta/dz$.
(e) Pollution-spreading parameter as measured by hourly surface winds at Pittsburgh Airport, reciprocal of daily harmonic average winds in miles per hour.
(f) Vertical-pollution spreading parameter as measured by surface and two thousand foot winds, Pittsburgh Airport, reciprocal of daily harmonic average wind shear in miles per hour per 1,000 feet.
(g) Visibility parameter, as measured by hourly visibilities at Pittsburgh Airport, reciprocal of daily average visibilities in miles.
(h) Smoke-top parameter, from in-flight reports recorded at Pittsburgh Airport, reciprocal of smoke-top heights above sea level in thousands of feet.

foot (above sea level) readings of the four times daily pilot-balloon observations made at the Pittsburgh airport during the period October 25–31. A running graph of the reciprocal of the daily harmonic average wind shear, computed similarly to the wind-parameter values plotted in figure 82 (e), is given in 82 (f). While quantitative conclusions should not be drawn from shear values computed so approximately, it is interesting to note that the trend of the shear parameter again resembles that of the stability.

Figure 82 also gives the prevailing wind direction for each day at Donora. (See table 68 for actual values used in fig. 82.) A detailed inspection of the winds recorded at the Donora Cooperative Observer Station shows wind from the northwest at an average speed of 3.6 miles per hour between 0001 EST on the 29th to 1100 EST the same day, a shift to northeast for one hour, an east wind from 1200 until 2100 EST at an average speed of 0.9 mile per hour, two hours of north wind at 2.5 miles per hour and finally a return to the northwest wind until 1100 EST on the 30th. The wind then shifted from the northwest to north for 1 hour, to east for another hour, then to southeast where it remained until noon of the 31st. During the process of shifting from northwest to southeast over a period of 3 hours the average speed was 0.5 mile per hour. Figure 83 shows in detail the hour-by-hour wind directions and speeds for October 29 and 30.

Table 69 shows simultaneous wind observations at Donora and Pittsburgh airport for the month of October 1948, surface as well as upper air winds being given for Pittsburgh. A definite shift can be seen in all three sets of wind observations between the 29th and 30th.

Visibility at the airport was restricted during the entire critical period. Since the restriction was due partly to smoke and partly to fog, the complicating factor of atmospheric humidity must be considered before satisfactory relations between visibility and pollution can be ascertained. Nevertheless, in a qualitative sense the visibility behaved about as might be expected—inversely as the pollution concentration which probably existed at Donora. Figure 82 (g) contains a running graph of the reciprocal of the daily average visibility at the airport from October 25 through November 1, and bears a definite resemblance to the graphs of the other parameters.

Fragmentary pilot reports, collected at the Pittsburgh Weather Bureau Airport Station, are available with respect to height above sea level of the top of the smoke layer. Since greater pollution concentrations can be expected with lower smoke tops, the reciprocals of the smoke-top values were computed. Figure 82 (h) contains a running graph of the values obtained for the period October 25–31. No values were available for the 28th. Otherwise, the graph again resembles the others, with a steady rise in the smoke-top parameter to a maximum at the end of the critical period. At 0950 EST of the 31st the top lay between 1,500 and 1,600 feet (producing the highest value of the smoke-top parameter), at 1100 EST the top had begun to rise between 1,600 and 1,700 feet, and at 1118 EST a pilot flying at 5,000 feet over Cumberland, Md., reported that he was in smoke and haze with a visibility of 5 miles.

Table 69.—*Wind data, October 1948, Pittsburgh Airport and Donora*

Date (1948)	Time (EST)	Prevailing surface wind direction for the day at Donora, 761 feet	Wind direction and speed, miles per hour, Pittsburgh Airport pilot-balloon observations: 1,250 feet (surface)	2,000 feet
Oct. 25	0400	NW	N 7	N 11
	0958		N 10	N 11
	1600		NW 8	NW 25
	2206		NW 4	NNW 9
Oct. 26	1145	NW	W 6	NW 4
	1600		WSW 3	W 8
	2211		SE 3	N 7
Oct. 27	0407	SW	SSW 4	NW 5
	1005		W 2	NW 3
	1620		ENE 2	N 4
	2208		SE 4	ESE 4
Oct. 28	0435	NW	NE 8	ENE 9
	1027		NNE 2	ENE 2
	1610		NNW 3	N 6
	2159		NNW 4	NNW 3
Oct. 29	0412	NW	NW 0	N 2
	1003		NNE 0	NE 4
	1615		NNW 3	N 5
	2208		N 6	N 5
Oct. 30	0400	SE	ESE 3	E 5
	1001		E 2	NE 3
	1600		NNE 3	N 2
	2203		SE 5	S 3
Oct. 31	0400	W	SSE 10	SSW 14
	1000		S 10	SW 12
	1605		SSW 8	SSW 19

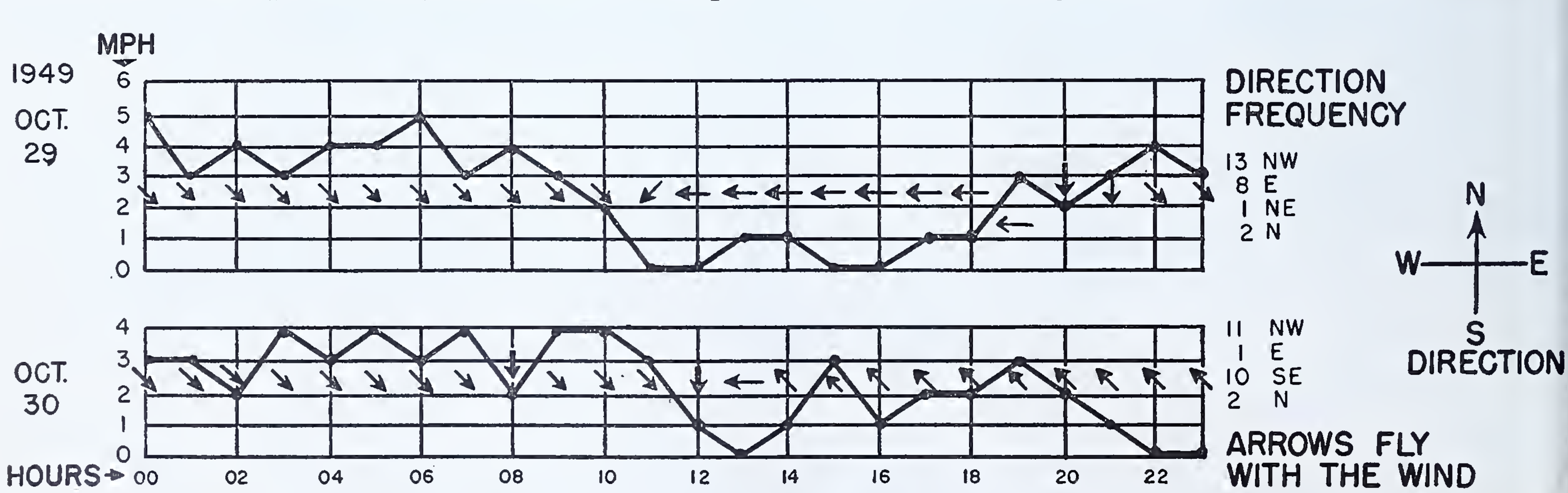


Figure 83.—*Hour by hour wind directions at Donora, Pennsylvania, for 29 and 30 of October 1948, as recorded by the Donora cooperative weather instruments.*

As already mentioned, the Donora occurrence of 1948 was not a unique one. A sequence of meteorological circumstances during the period October 4–14, 1923, had also brought about serious smog conditions in the vicinity of Donora. The synoptic situation was quite similar to that of October 1948. Following passage of a cold front, a large polar anticyclone moved into the area surrounding southwestern Pennsylvania, stagnated for many days, and was finally displaced by a frontal system from the west. There is a report of yet another serious smog period at Donora during the period October 7–18, 1938. Again a stagnating polar anticyclone dominated the weather maps. In this case, however, there were two such anticyclones—one persisting from the 9th through the 12th and the other from the 14th through the 18th. Frontal passages occurred on the 6th, 8th, 13th, and 19th. On the 7th a rapidly moving polar anticyclone, passing over the northeastern portion of the United States, caused one preliminary day of the weak winds and low-level stability which seems to be requisite to intense pollution concentrations near the ground.

CONCLUSIONS

This report has presented the results of a micrometeorological investigation of the Monongahela River Valley in the vicinity of Donora, Pa., and a description of the meteorological conditions during the Donora smog episode of October 1948. From these findings the following conclusions may be drawn:

A. Micrometeorology of the valley for the period February 14, to April 28, 1949:

1. Smoky periods were caused by the occurrence of strong atmospheric stability and stagnation of the air in the valley as well as some thousands of feet above the valley.

2. Anticyclones of polar origin often accompanied these conditions of strong stability and calm or light winds through a great depth of the atmosphere.

3. Stagnation alone did not cause an accumulation of smoke in the valley as was demonstrated by nonsmoky periods with light to calm winds. These periods occurred when fresh, unstable polar air, behind a vigorously moving cold front, lay over the area.

4. Stability alone did not cause an accumulation of smoke. During windy periods with stable atmospheric conditions above the hilltop level, smoke was carried out of the valley.

5. Midvalley height stations on the east side of the valley all indicated flow parallel to the valley orientation at times of very stable conditions when the drainage current was deep enough to reach them, and down slope flow at other times when the main valley drainage current was more shallow and only the valley-side drainage flow affected the stations.

6. During periods of very stable conditions the main valley drainage current in the lower portion of the valley came from down river.

7. Due to the turbulence of gravity currents operating all night on very stable nights, smoke, as determined by morning visual observations, apparently was evenly distributed throughout the valley longitudinally, laterally, and vertically.

8. During moderate to strong winds, turning effects within the valley were imposed upon the hill top wind direction; wind speeds in the valley along the valley sides were decreased in proportion to the depth in the valley and were lower on the lee side than the windward side. The decrease of speed with depth along the valley sides was greater for cross valley flow than for flow parallel to the valley.

B. Meteorology of the smog episode of October 25–31, 1948:

1. The Donora smog episode of October 25–31, 1948, was an extreme case of the "smoky morning" type described in this paper.

2. Willett (*12*), in examining weather records for the past 30 years, has shown that occurrences of meteorological conditions similar to those at Donora in late October 1948, may be expected on the average once in every 10 or 15 years with no guarantee that they would not occur in consecutive years or months or twice in the same month. Other notable stagnant meteorological periods occurred in October 5–13, 1923, and October 7–18, 1938.

3. Dense fog in the valley persisted past midday for four consecutive days, which maintained a high albedo during the period, and prevented heating of the valley floor.

4. Wind speeds remained less than 7 miles per hour from the surface to 5,000 feet for a period of three consecutive days, showing that the atmosphere lacked the ability to remove contaminants rapidly.

5. Four-day presence of maximum temperatures at Donora below those at the Pittsburgh airport shows the persistence of extreme valley stability for four consecutive days.

6. An extensive high pressure area covered the eastern United States and persisted over the Appalachian region.

C. General requirements for recurrence of smog conditions:

1. Pollution—Sources must be near and active.

2. Topography—Terrain favorable for the low-level trapping of air indicates potentially dangerous areas.

3. Humidity—Moisture in the lowest layers should be such that fogs can form and persist and so reflect the sunlight which might otherwise destroy the inversion.

4. Meteorological Model (*16*)—A polar anticyclone reinforced by upper air anticyclogenesis appears to be the meteorological model most likely to produce the stagnant conditions required for the great pollution concentrations.

5. Season—October appears to be the month with the highest probability of occurrences of intense atmospheric stability and stagnation in the area of Donora. (See Appendix III.)

ACKNOWLEDGMENTS

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METEOROLOGICAL CONDITIONS AND ATMOSPHERIC CONTAMINANTS

Harold J. Paulus, W. H. Hoecker, Jr., and Herbert H. Jones

One of the objectives of the Donora investigation was the correlation of the concentration of atmospheric pollutants in the Monongahela Valley and meteorological factors. In this section these correlations and their importance are discussed. The application of the results to a program designed to prevent recurrence of unusual smog affections is presented. A discussion follows of the relationship between wind direction, wind speed, relative humidity, and temperature, and concentration of the various airborne contaminants.

CONTAMINANTS IN RELATION TO WIND DIRECTION

Figures 84 to 87 inclusive show the average concentrations of the various contaminants in relation to wind direction and air sampling station. The term "no sample" at a particular station in the figures indicates that the wind was not blowing from the given direction at the time samples were collected. Figure 84 shows wind direction and concentration by air sampling station for sulfur dioxide. There were no outstanding differences indicated for the various wind directions and stations. The high value for station No. 10 with a southeast wind was obtained on a single sample collected during a fog.

Figure 85 shows wind direction and concentration by air sampling station for total sulfur, as SO_2. When the wind was from the northwest the higher values appeared at stations 3, 4, and 12, but when the wind shifted to the west the concentration at station No. 5 increased, and stations 3, 4, and 12 remained relatively high. This indicates the possible influence of the residential area on the concentration at station No. 12, and the zinc plant on the remaining stations with high concentrations. When the wind was from the southwest, the concentration of total sulfur at the different stations was of the same general order of magnitude. The high value for station No. 1 was influenced by a sample taken during an inversion. When the wind was from the south, high concentrations were obtained at stations 1, 2, 3, 10, and 12. The high concentrations at stations 2 and 3 may have been influenced by residential or business areas; stations 1 and 10 by residential or outside sources; and the high concentration at station No. 12 by the steel plant. Only a few samples were obtained when the wind was from the southeast, east, northeast, and north as winds from these directions occurred infrequently.

Total particulate matter in figure 86 shows about the same pattern of distribution by stations as total sulfur. The southwest wind does not show as great a leveling effect on concentration at the various stations. The sources of this contaminant are apparently the same as those for total sulfur. Only a few samples were obtained when the wind was from the southeast, east, northeast, and north as winds from these directions occurred infrequently.

Figure 87 shows wind direction and concentration by air sampling stations for zinc. Since the zinc plant is the main source of the zinc, stations 3 and 4, as would be expected, had a high concentration with the wind from the northwest; stations 4 and 5 with the wind from the west; station No. 3 from the south; station No. 2 from the east; and station No. 3 from the north. The high average value for station No. 2 with the wind from the south and for station No. 5 with the wind from the southeast were influenced by samples collected during very low wind speeds.

Graphical presentations prepared for lead and cadmium showed a similar pattern to that of zinc.

CONTAMINANTS IN RELATION TO WIND SPEED

The distribution of six atmospheric constituents found in the Donora area are shown in table 70 according to three ranges of wind speed, 0–3, 4–9, and 10–22 miles per hour. The following tabulation, indicating the percentage of samples greater than a certain arbitrary concentration, shows the influence of wind speed on the concentration of the contaminants in the general atmosphere.

Wind speed (miles per hour)	Constituent and concentration					
	Sulfur dioxide, 0.20 or greater ppm	Total sulfur, as SO_2, 0.30 or greater ppm	Total particulate matter, 1.5 or greater mg/m^3	Zinc, 0.10 or greater mg/m^3	Lead, 0.01 or greater mg/m^3	Cadmium, 0.002 or greater mg/m^3
	Percent of air samples					
0–3	21. 8	18. 7	20. 7	15. 5	17. 2	17. 2
4–9	8. 7	10. 2	7. 4	9. 6	1. 6	15. 9
10–22	17. 2	17. 2	9. 4	22. 7	15. 1	30. 2

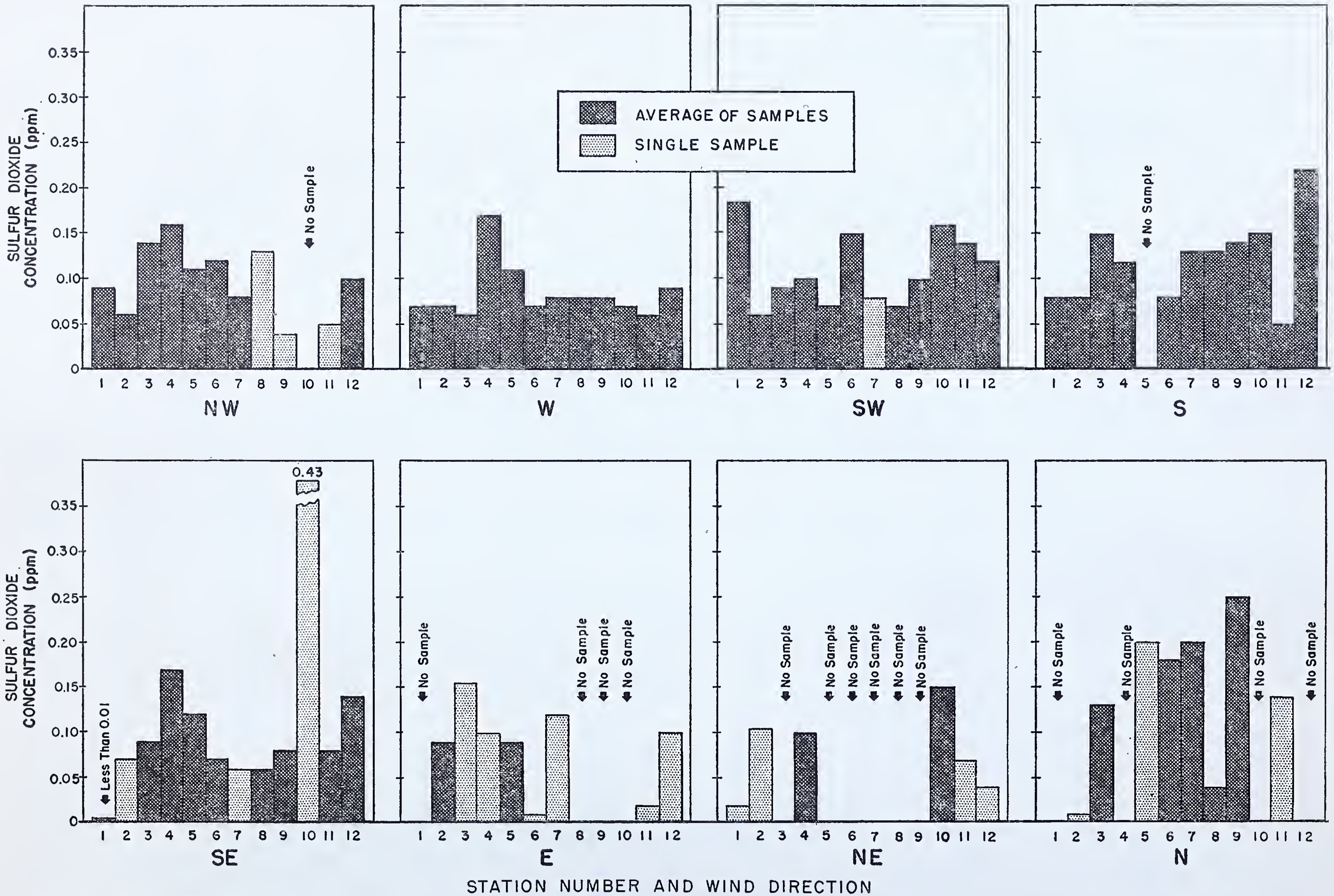

FIGURE 84.—*Average sulfur dioxide concentration by wind direction and station. The term "no sample" at a particular station indicates that the wind was not blowing from the given direction at the time the samples were taken.*

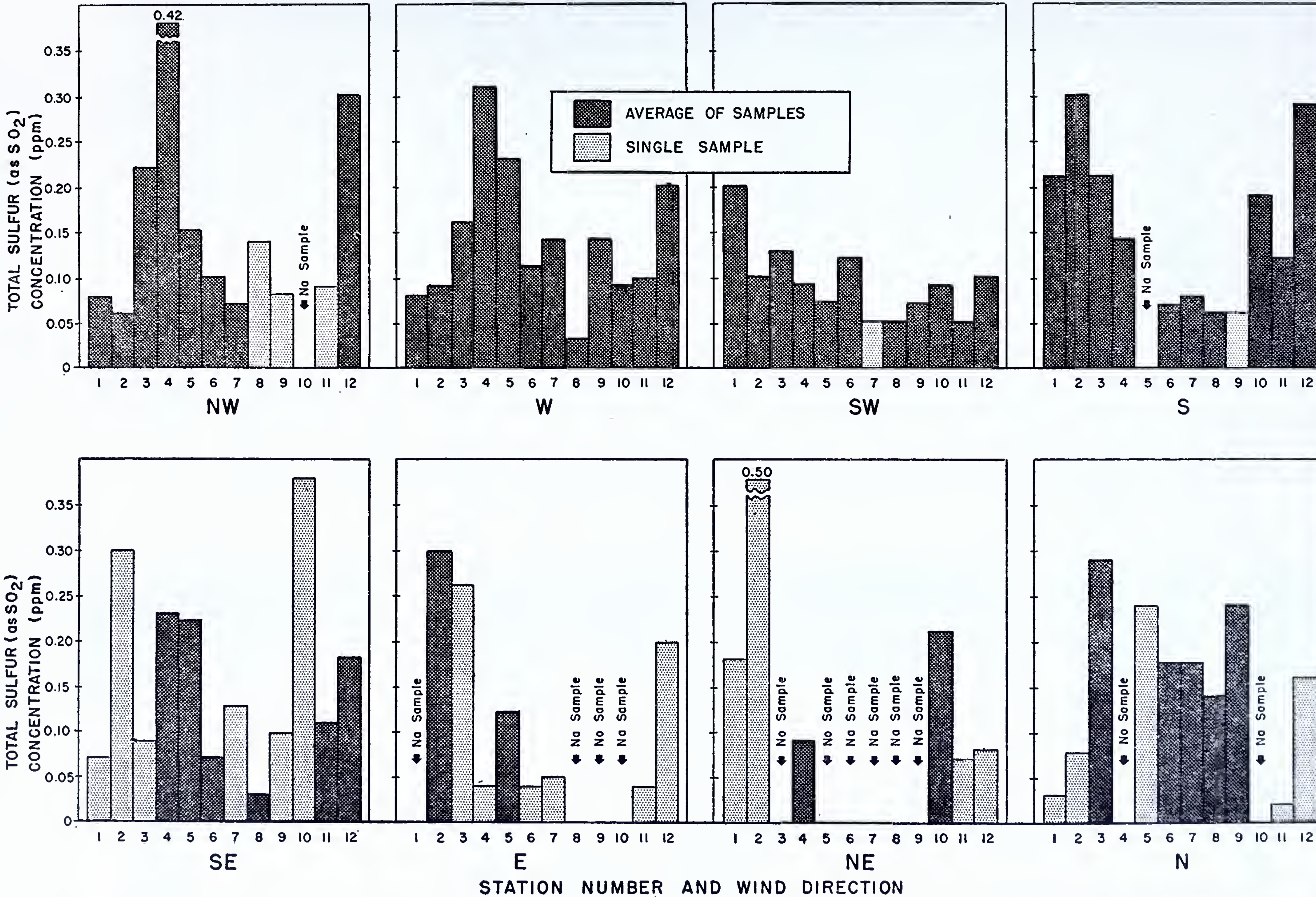

FIGURE 85.—*Average total sulfur (as SO_2) concentration by wind direction and station. The term "no sample" at a particular station indicates that the wind was not blowing from the given direction at the time the samples were taken.*

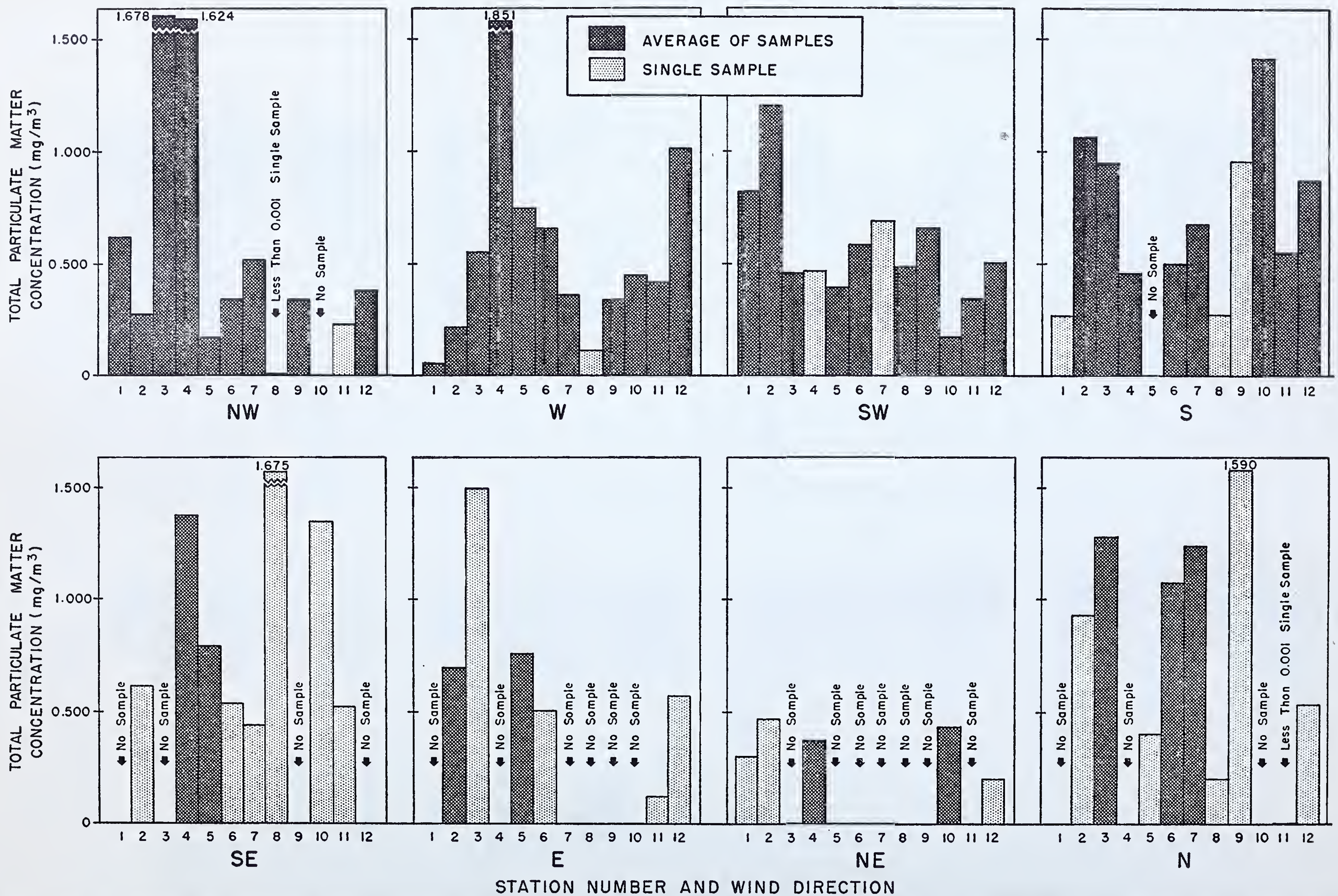

FIGURE 86.—*Average total particulate matter concentration by wind direction and station. The term "no sample" at a particular station indicates that the wind was not blowing from the given direction at the time the samples were taken.*

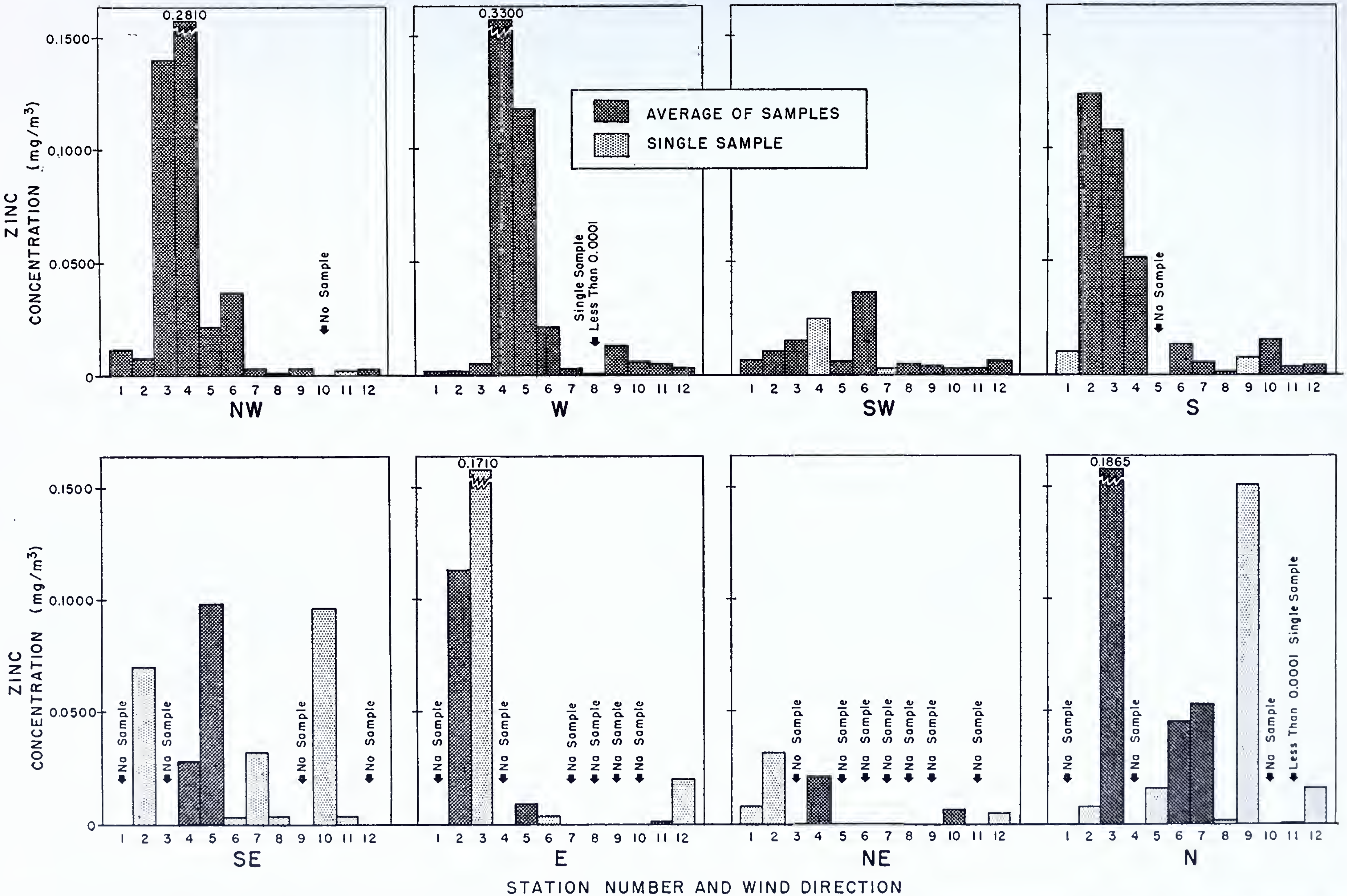

FIGURE 87.—*Average zinc concentration by wind direction and station. The term "no sample" at a particular station indicates that the wind was not blowing from the given direction at the time the samples were taken.*

TABLE 70.—*Distribution of atmospheric constituents found in the Donora area from Feb. 16 through Apr. 27, 1949, according to wind speed*

Concentration range	Total number of samples	Wind speed (miles per hour) 0–3	4–9	10–22
	Sulfur dioxide (parts per million)			
Total	260	75	127	58
0.00–0.09	145	33	80	32
0.10–0.19	78	26	36	16
0.20–0.29	21	6	8	7
0.30–0.39	9	7	0	2
0.40–0.49	4	2	1	1
0.50 or over	3	1	2	0
	Total sulfur (parts per million)			
Total	267	76	127	64
0.00–0.09	117	23	65	29
0.10–0.19	88	24	43	21
0.20–0.29	24	15	6	3
0.30–0.39	18	6	8	4
0.40–0.49	8	1	3	4
0.50 or over	12	7	2	3
	Total particulate matter (milligrams per cubic meter)			
Total	205	58	94	53
0.0–0.4	95	15	49	31
0.5–0.9	65	26	27	12
1.0–1.4	21	5	11	5
1.5–1.9	9	5	3	1
2.0–2.4	7	3	2	2
2.5 or over	8	4	2	2
	Zinc (milligrams per cubic meter)			
Total	205	58	94	53
0.00–0.09	175	49	85	41
0.10–0.19	13	5	3	5
0.20–0.29	5	2	1	2
0.30–0.39	5	1	2	2
0.40–0.49	3	1	1	1
0.50 or over	4	0	2	2
	Lead (milligrams per cubic meter)			
Total	205	58	94	53
0.000–0.009	186	48	93	45
0.010–0.019	14	7	1	6
0.020–0.029	2	1	0	1
0.030 or over	3	2	0	1
	Cadmium (milligrams per cubic meter)			
Total	205	58	94	53
0.0000–0.0009	149	41	73	35
0.0010–0.0019	15	7	6	2
0.0020–0.0029	12	5	3	4
0.0030–0.0039	8	2	3	3
0.0040–0.0049	1	0	0	1
0.0050 or over	20	3	9	8

In general, the greater percentage of higher values for all the contaminants was found in the wind speed range 0–3 miles per hour. One would expect the concentrations to decrease with increasing wind speed; however, this is not indicated by the data shown in the above table since the smallest percentage of high concentrations was found in the intermediate wind speed range of 4–9 miles per hour. A possible explanation of this finding is that the high wind speed caused the effluent stream to level off at height of discharge, and due to the terrain the contaminants impinged on the sides of the hills and became dispersed in the valley. Also at high wind speeds, turbulences carry the effluent downward from the stack thereby creating a higher concentration. At intermediate speeds the effluent is carried upward by thermal buoyancy and then dissipated by the wind.

CONTAMINANTS IN RELATION TO TEMPERATURE AND RELATIVE HUMIDITY

The ambient temperatures were divided into three ranges: Less than 40° F., 40–60° F., and 61° F. and greater, and also into five ranges, less than 35° F., 35–44° F., 45–54° F., 55–65° F. and greater than 65° F. The results of the analyses of all samples collected in these various temperature ranges were averaged. No definite trends or relationship between concentration and the temperature ranges were observed.

The values for relative humidity were divided into five ranges: 0–40 percent, 41–55 percent, 56–70 percent, 71–85 percent, and 86–100 percent. The results of the analyses of all samples collected with a relative humidity value within a particular range were averaged. In general, the average values of the concentrations of the contaminants for the different humidity ranges show only a moderate variation which would indicate that relative humidity had little influence on concentration.

CONTAMINANTS IN RELATION TO ATMOSPHERIC STABILITY

A temperature inversion was indicated by Weather Bureau instruments from 8 p. m. April 20 to 9 a. m. April 21, 1949. The temperature difference between valley top and valley bottom varied between 2° F. and 5° F. or $\Delta\ \theta/1000$ feet varied between 11° F. and 19° F. During the inversion the wind directions were northerly in the valley bottom, easterly and southerly with very low speeds at midvalley height and southerly at valley top. Visibility at 7:30 a. m. April 21 was not more than four city blocks.

Results of the analyses of the samples collected during this temperature inversion are shown in table 71. For comparison average values of samples collected during the "test period" (April 18 to April 21), excluding the inversion period samples, are included. The average values for the inversion period samples show a greater than twofold increase for sulfur dioxide, total sulfur and total particulate matter, and a large increase for zinc, lead and cadmium, over the average value of the other samples taken during the "test period."

To show the relationship between atmospheric stability and the concentration of contaminants, the variation of the stability factor with time during April 20–21, 1949, and ob-

TABLE 71.—*Results of the analyses of air samples collected during a temperature inversion from 8 p. m. Apr. 20 to 9 a. m. Apr. 21, 1949*

Time	Station number	Relative humidity	Sulfur dioxide (ppm)	Total sulfur as SO_2 (ppm)	Total particulate matter (mg/m^3)	Zinc (mg/m^3)	Lead (mg/m^3)	Cadmium (mg/m^3)
10 p. m.	2	64	0.15	0.56	2.470	0.4870	0.0314	0.0084
10 p. m.	3	63	.16	.26	1.500	.1710	.0084	.0034
1 a. m.	1	66	.58	.74	3.000	.0222	.0080	.0000
1 a. m.	10	62	.26	.30	2.020	.0200	.0065	.0146
4 a. m.	6	62	.15	.23	1.380	.0017	.0028	.0001
7 a. m.	3	66	.42	.71	5.320	.3120	.0309	.0032
7 a. m.	12	56	.55	.84	2.750	.0092	.0060	.0003
Averages during inversion	----	----	.32	.52	2.634	.1461	.0134	.0043
Averages omitting inversion	----	----	.12	.21	1.195	.0925	.0073	.0024

ppm: Parts of substance per million parts of air by volume.
mg/m^3: Milligrams of substance per cubic meter of air.

served values of sulfur dioxide and total particulate matter are presented in figure 88.

The stability factor increased sharply between 7 p. m. and 10 p. m. on April 20 and then maintained about the same level until 9 a. m. on April 21 when the value decreased rapidly. In general, the values for sulfur dioxide and total particulate matter increased during the stable period and decreased rapidly when the stability factor decreased. The values for sulfur dioxide (0.15 ppm) and total particulate matter (1.38 mg/m^3) collected at station No. 6 in Webster Hollow (at 4 a. m.) did not follow the general pattern and are not shown in the figure. This may be explained by the fact that the main valley floor airflow was from the north and the Webster Hollow airflow was from the east.

The general effect of valley atmospheric stability on the concentration of the various contaminants was investigated by plotting concentration values against the stability factor $d\Theta/dz$. A definite grouping of low concentrations for unstable valley atmospheric conditions and high concentrations for stable valley conditions was noted. Figure 89 illustrates this relationship for total particulate matter.

Two Stable Periods Compared

Since information is not available on the concentration of contaminants that existed during the October 1948 episode, which was an extended period of stability, it is of interest to compare the weather conditions of the October period with those of April 20–21, 1949.

The *general weather conditions* for the two periods were as follows:

1. *Movement.*—The high pressure area of October 1948 scarcely moved between October 25 and October 30 once it become centered over the eastern United States, while the anticyclone (causing the stability) of April 20–21, 1949, had a regular eastward movement between April 18 and 22, from eastern South Dakota to eastern North Carolina.

2. *Area.*—The anticyclone of October 25–30, 1948, dominated the United States from the Sierra-Nevada Range eastward, while that of April 20–21, 1949, covered a relatively small area.

3. *Path.*—The center of the anticyclone of October 25–30, 1948, moved eastward toward Pennsylvania from Minnesota, then stagnated over western Pennsylvania and central New York; the center of the anticyclone of April 20–21, 1949, moved east-southeast from South Dakota to eastern North Carolina, actually passing 4° latitude south of Donora.

4. *Upper air stability.*—A very stable layer existed at hilltop level from 10 p. m. October 27 until 10 a. m. October 31, 1948, and was about 500 feet thick; a stable layer existed above the very stable layer. In the inversion period of April 20–21, 1949, the only recorded inversion at hilltop level was at 10 p. m. on the 20th of April when a very stable layer (inversion) about 400 feet thick existed, but by 10 a. m. of the 21st of April this layer had become very unstable, allowing excellent mixing.

5. *Origin.*—Both anticyclones were of polar origin entering the northern border of the United States near North Dakota or Montana.

The *valley weather conditions* for the two periods were as follows:

1. Dense fog well past noon occurred for four consecutive days during October 27–30, 1948, while no fog was observed during April 20–21, 1949.

2. The average valley stability factor for both inversion periods was about the same although higher peak values were reached in the October inversion.

3. Valley winds were light in both periods.

It is seen, therefore, that in only three respects were the meteorological conditions similar: (*a*) Origin of the anticyclones, (*b*) degree of valley stability, and (*c*) light wind speeds in the valley. Emphasis must be placed on the necessity of atmospheric stagnation concurrent with the high degree of stability. Stability accompanied by wind will not allow airborne contaminants to accumulate.

Onset of Illness

It was shown in figure 88 previously presented that the concentration of contaminants increased during a brief stable period. Figure 89 also showed the relation between concentration and stability. It may be assumed that the concentration of contaminants increased during the extended period of stability in October 1948. While it is not possible to estimate with any degree of accuracy the concentrations of the contaminants in the atmosphere during the October period, it is of interest to consider the relationship between the stability factor and the onset of illness which occurred during that period.

Figure 90 shows the valley stability factor and the onset of illnesses, both fatal (curve A) and nonfatal (curve B), during the period from Monday, October 25, to Sunday, October 31, 1948. Beginning on Friday, the points on the cumulative curves are plotted at the end of 6-hour periods. The stable air condition began on Tuesday, October 26, and extended through Saturday, October 30. Daily stability factors are shown for 7:30 a. m., 12 m., and 4:30 p. m., with the noon value the highest in each case. A general increase in the daily peak values may be noted until Friday noon, after which a decrease is shown.

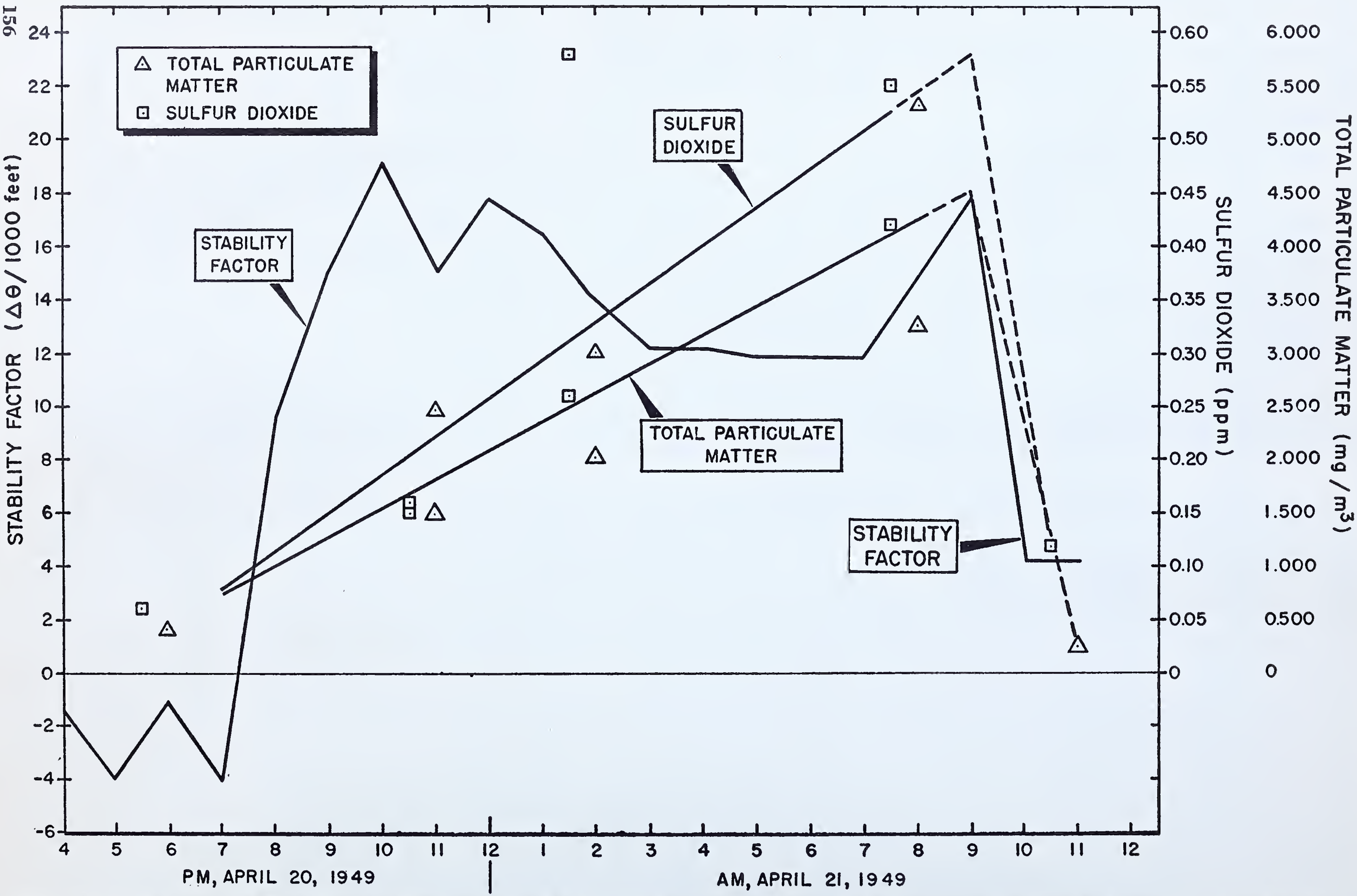

FIGURE 88.—*Variation of stability factor with time during April 20–21, 1949, and observed values of sulfur dioxide and total particulate matter. The solid straight lines showing a relation between the magnitude of the concentrations and the duration of the inversion were fitted by the method of least squares; the broken lines are introduced on the assumption that the concentrations continued to increase linearly till the end of the inversion period, and then decreased linearly.*

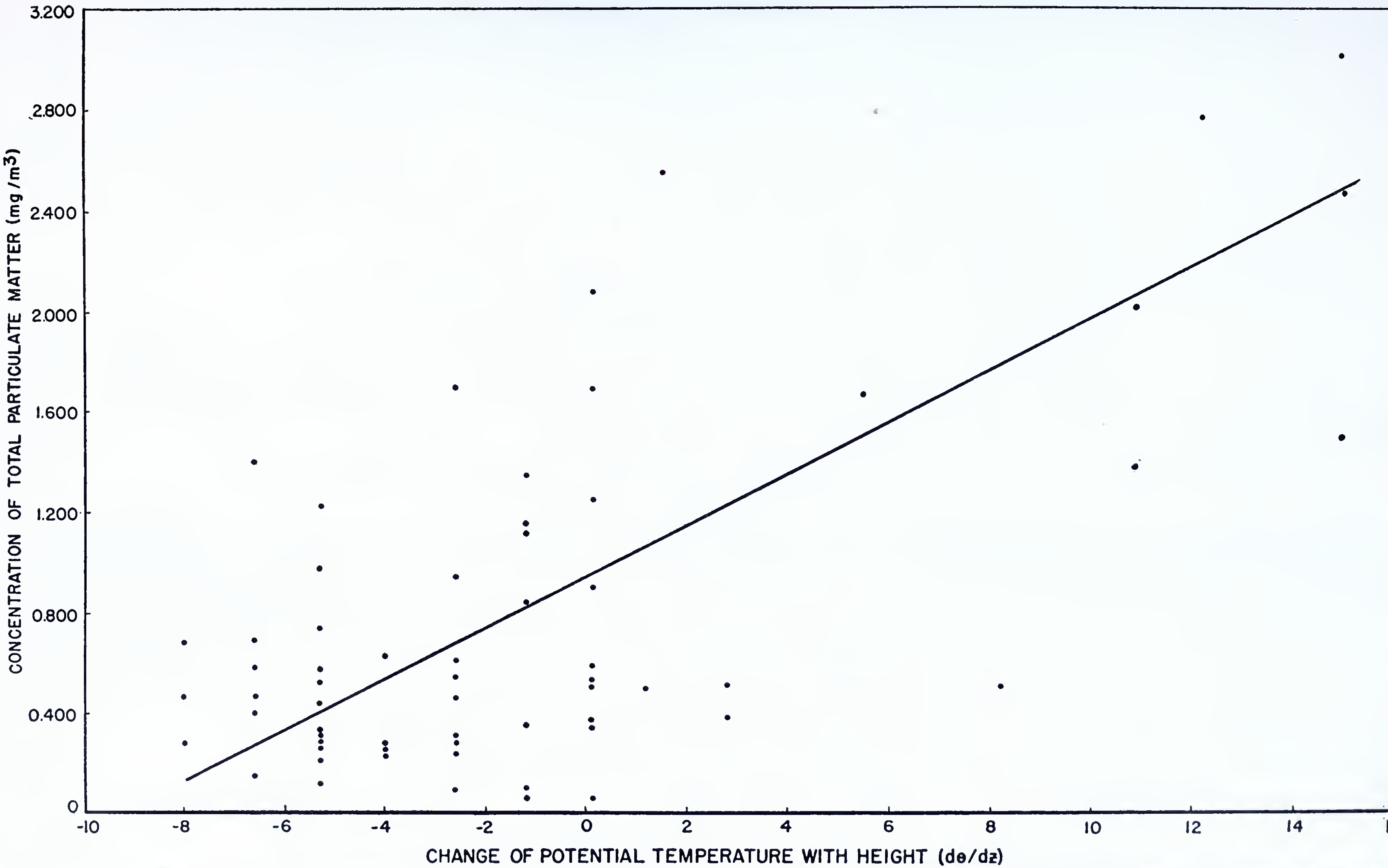

FIGURE 89.—*Scatter diagram showing the relation between the concentration of total particulate matter in the atmosphere and the change of potential temperature with height. The regression line was fitted by the method of least squares.* NOTE:—*A value of 5.32 mg/m^3 occurring with a value of $d\theta/dz$ of 12.2 was also used in determining the line.*

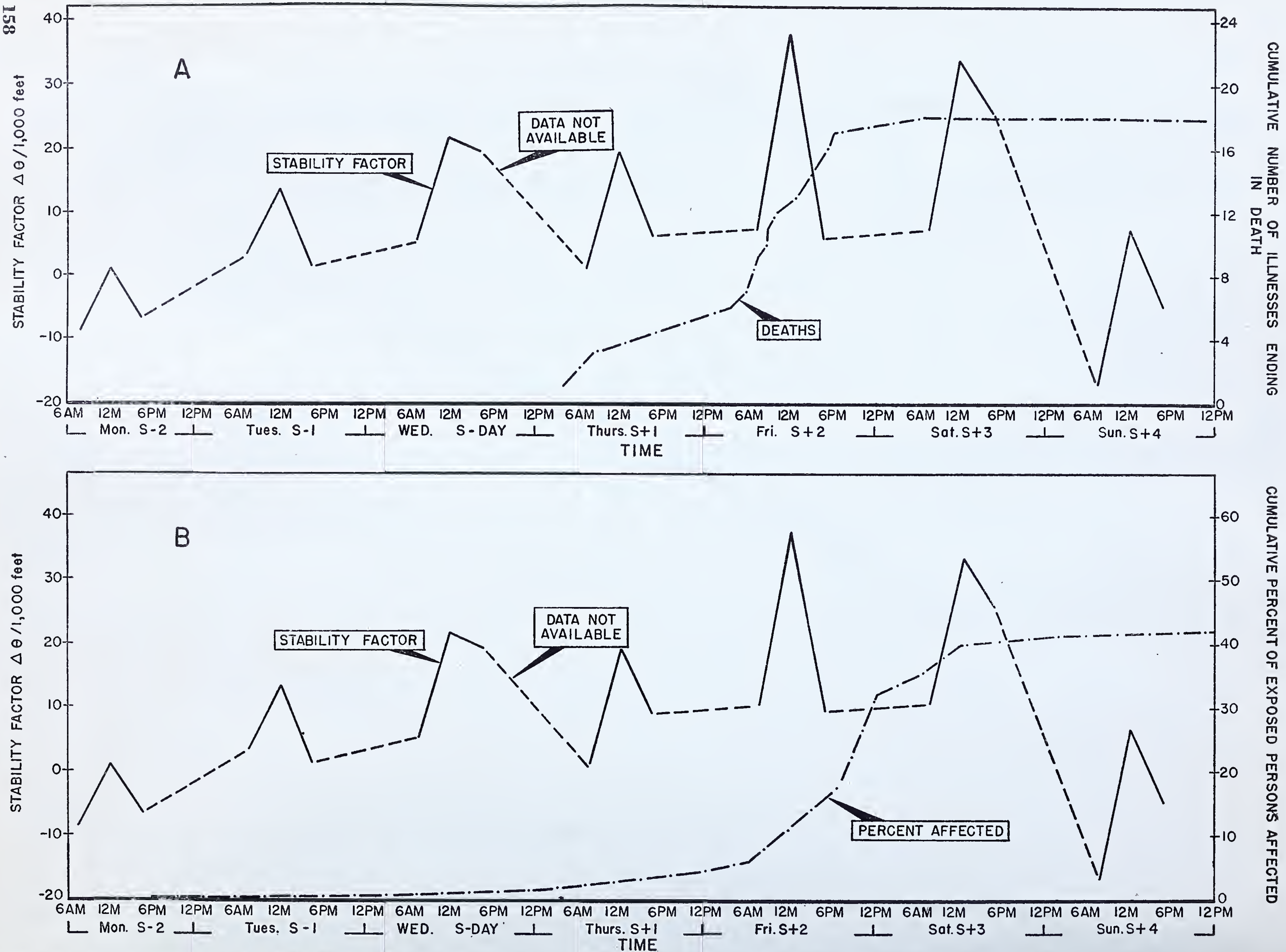

FIGURE 90.—*A. Variation of stability factor with time during October 25–31, 1948, and cumulative number of illnesses ending in death, according to time of onset of illness. B. Variation of stability factor with time during October 25–31, 1948, and cumulative percent of exposed persons affected according to time of onset*

The curve A of the time of onset of illness ending in death showed a sharp increase in the period 6 a. m. to 6 p. m. on Friday, during which period the greatest number of cases of onset of illness occurred. The curve B of the time of onset of nonfatal illnesses showed a marked increase in the period of 6 a. m. to 12 p. m. Friday. As shown in the figure the period of marked increase of onset of illness occurred on the fourth consecutive day with a positive stability factor and during the period of the greatest intensity of the stability factor.

RECOMMENDATION

Based on a detailed analysis of the data obtained on atmospheric pollutants and meteorological conditions, the following program to prevent recurrence of affections from unusual smog conditions is presented:

1. An alert shall be issued when an anticyclone of an extent similar to the one of October 25–30, 1948, approaches the eastern United States, is slowly moving, and shows indications of stagnation.

2. A warning to take preventive measures such as outlined below, shall be issued when the following conditions occur simultaneously for one day and show no indication for improvement.

a. An anticyclonic model as in (1) moves to the eastern United States;

b. Valley stability factor as determined by valley top and bottom temperatures and defined by $\Delta\Theta/1{,}000$ feet becomes and remains greater than 5.5° F.;

c. Valley winds less than 5 mph and upper air winds less than 10 mph;

d. Moderate to dense fog in the valley continues some time past noon.

The industries in the Donora area and adjacent communities should curtail production during a stable-stagnant valley air condition as outlined above. The extent to which production should be curtailed is dependent on the extent to which measures are instituted to reduce atmospheric pollutants. The greater the reduction attained, the less the curtailment that will be needed.

A committee of interested persons should be formed to carry out this recommendation and establish a program of action.

IV. Discussion of Cause of Episode

The data presented in the biological studies indicate that the clinical syndrome was characterized essentially by irritation of the respiratory tract which was especially severe in elderly persons and those with known chronic cardiorespiratory disease. The data indicate, furthermore, that the episode was not due to an accidental occurrence but rather resulted from the accumulation of atmospheric pollutants during an unusually intense and prolonged stable air condition. While the weather alone cannot be blamed for the episode, the fact that it played a significant role cannot be denied.

Following analysis and study of all available data, it is believed that unequivocal identification of the specific agent responsible for the illness is not justifiable. Nevertheless, with the assumption that the air contaminants during the smog period were no different from those of the period of study, except in a quantitative sense, it is of moment to consider the various substances studied with reference to the syndrome.

SUBSTANCES STUDIED

Since data were not available on the various atmospheric contaminants present during the smog, a survey was made of all possible sources of atmospheric contaminants in the Donora area; and, based on the findings from this survey, the following substances were selected for study: Sulfur dioxide, total sulfur, chloride, fluoride, oxides of nitrogen, arsine, stibine, hydrogen sulfide, carbon monoxide, carbon dioxide, and total particulate matter consisting essentially of carbon, silicates, and compounds of zinc, lead, cadmium and iron.

INDIVIDUAL SUBSTANCES IN RELATION TO CLINICAL SYNDROME

Since irritation of the respiratory tract was the clinical syndrome developed by the exposed humans and animals in the community, the following substances can be eliminated when considered as *single* causative agents, since, among other reasons, they are neither known nor suspected to be respiratory tract irritants: Carbon monoxide, arsine, stibine, zinc oxide, ferric oxide, lead oxide, carbon, silicates, and carbon dioxide. It is to be noted that oxygen deficiency may also be eliminated as a possible factor for similar reasons.

There is thus left for further evaluation as the possible respiratory tract irritants the following: fluoride, chloride, oxides of nitrogen, hydrogen sulfide, cadmium oxide, and sulfur dioxide together with its oxidation products. Each of these agents will be considered separately.

Fluoride

Fluoride, possibly as hydrogen fluoride and sodium fluoride, was found in the engineering study to be present in exceedingly small amounts in the atmosphere during the sampling periods. The best available information indicates that such low levels of fluoride, either as hydrogen fluoride or sodium fluoride, would not cause the respiratory irritation that was observed. Corroborative data were supplied by the biological studies since no evidence of chronic effects from fluoride was found. It seems reasonable, therefore, to say that since the concentration of fluoride found in the atmosphere was relatively low, and further since no evidence of chronic effects was found, the possibility is slight that toxic concentrations of fluoride accumulated during the October 1948 episode.

Chloride

The concentrations of chloride, possibly as hydrogen chloride and zinc chloride, found in the atmosphere during the investigation were of such low order of magnitude that the possibility is remote that levels accumulated during the October 1948 episode were capable of producing the syndrome observed.

Oxides of Nitrogen

The concentrations of oxides of nitrogen found in the atmosphere during the investigation were of such low order of magnitude that the possibility is remote that levels accumulated during the October 1948 episode were capable of producing the syndrome observed.

Hydrogen Sulfide

Hydrogen sulfide may be ruled out as a possible causative agent since the results obtained indicated that if it were present, it existed only in trace amounts.

Cadmium Oxide

The concentrations of cadmium, probably as cadmium oxide, found in the atmosphere during the investigation were of such low order of magnitude that the possibility is remote that levels accumulated during the October 1948 episode were capable of producing the syndrome observed.

Sulfur Dioxide and Its Oxidation Products

The amounts of sulfur dioxide and total sulfur discharged into the atmosphere from various sources in the community were significant constituents of the over-all atmospheric pollution load. However, the levels of sulfur dioxide found in the general atmosphere *during the investigation* are not considered capable of producing the syndrome observed. It is,

of course, not known what levels were reached during the smog period, and hence, whether or not levels capable of producing the syndrome were reached at that time. Further, it is known that sulfur dioxide can be oxidized to sulfur trioxide in the atmosphere. It is not possible, however, to estimate the extent of oxidation and the role that sulfur trioxide may have played. That it could have had a significant effect is a possibility. It appears doubtful, however, that either sulfur dioxide or sulfur trioxide, acting individually or together, reached levels that were capable of producing the syndrome.

Summary

It does not appear probable from the evidence obtained in the investigation that any one of these substances (irritant or nonirritant) *by itself* was capable of producing the syndrome observed. However, a combination of two or more of these substances may have contributed to that syndrome.

COMBINATION OF SUBSTANCES IN RELATION TO CLINICAL SYNDROME

It is well known that one substance may influence the physiologic action of another, and it is possible that there was a summation of the action of the individual irritant constituents which produced an effect greater than would be anticipated for any one of the individual constituents. Moreover, there is evidence which indicates that the effect of irritant gases can be enhanced by adsorption on particulate matter. In addition to enhanced action, gases may be carried deeper into the respiratory tract than they would normally be carried in the absence of such particulate matter. This action then would carry the noxious substance into the lower levels of the respiratory system where the more damaging effects would be produced.

It is known that irritant gases exert their effect in the respiratory tract depending largely on their solubilities; that is, compounds which are highly soluble exert their effect in the upper respiratory tract while compounds which are less soluble exert their primary action in the deeper parts of the lung. A gas, therefore, such as sulfur dioxide which would normally exert its primary action in the upper part of the respiratory tract might produce more serious effects if it were transported to the deeper parts of the lungs, as for example, by particulate matter. Both solid particulate matter and liquid particulate matter (fog) were present in the atmosphere in large quantities during the October 1948 episode.

Another influencing factor to be considered is carbon dioxide which was probably a significant contributor to the overall atmospheric pollution load. Because carbon dioxide is a respiratory stimulant, it may have contributed to the effects produced by other contaminants by virtue of the increase in depth of respriation which it induces.

SUMMARY

It seems reasonable to state, on the basis of the previous discussion, that while no *single* substance was responsible for the October 1948 episode the syndrome could have been produced by a combination, or summation of the action, of two or more of the contaminants. Sulfur dioxide and its oxidation products, together with particulate matter are considered significant contaminants. However, the significance of the other irritants as important adjuvants to the biological effects cannot be finally estimated on the basis of present knowledge.

It is important to emphasize that information available on the toxicological effects of mixed irritant gases is meager and that data on possible enhanced action due to adsorption of gases on particulate matter is limited. Further, available toxicological information pertains mainly to adults in relatively good health. Hence, the lack of fundamental data on the physiologic effects of a mixture of gases and particulate matter over a period of time is a severe handicap in evaluating the effects of atmospheric pollutants on persons of all ages and in various stages of health.

V. Summary and Recommendations

Summary of Biological Studies

1. During the smog of October 1948 a total of 5,910 persons, or 42.7 percent of all persons in the Donora area, were affected to some degree by the smog.

2. The affection was essentially an irritation of the respiratory tract and other exposed mucous membranes, and varied in degree from mild to severe. Cough was the predominant single symptom during the illness.

3. Classified as to degree of affection, 2,148 persons, or 15.5 percent of the total population in the area, were mildly affected; 2,322 persons or 16.8 percent were moderately affected, and 1,440 persons or 10.4 percent were severely affected by the smog.

4. Neither incidence nor severity of affection appeared to be influenced by sex, race, occupational status, length of residence in the area, or degree of physical activity at time of onset of affection.

5. Both incidence and severity revealed a direct relationship with increasing age. Over 60 percent of persons 65 years of age and over reported some affection from the smog, and almost one-half of these were in the severely affected group.

6. The population of Webster reported a higher incidence of affection of each degree than in the area as a whole. Age-specific rates for Webster revealed an age pattern similar to the corresponding area pattern, but at a higher level.

7. Although onset of affection began in some cases as early as S-day (the first day of severe smog), the larger number of persons became ill on day No. 2 (the second day after S-day). About 40 percent of affected persons reported onset of affection between 6 p. m. and midnight of day No. 2.

8. Twenty persons died in the Donora area during or shortly after the smog of October 1948; 17 died on day No. 3.

9. Based on data available for 18 of the persons who died, the death rate was significantly higher in the nonwhite than in the white population, and was significantly higher for Webster than for the area as a whole.

10. The ages of the persons who died ranged from 52 to 84 years with a mean of 65 years.

11. Principal past employment, duration of residence in the community, and sex played no significant part in the occurrence of the fatal illnesses.

12. Only in the degree of severity and in the outcome were the fatal cases different clinically from the severely ill persons who did not die.

13. Preexisting disease of the cardiorespiratory system appeared as a single significant factor among the fatally ill, although in four cases, no history of any chronic disease prior to the smog was obtained.

14. In spite of the apparent association between cardiorespiratory disease and smog affection, no significant difference appeared in the occurrence of pulmonary emphysema in a group of persons who had been ill during the smog, and in a nonaffected group.

15. Epidemic influenza did not play a part in the illnesses which occurred during the smog.

16. Some relationship appeared between severity of affection and certain characteristics of housing quality.

17. In addition to the persons who became ill during the smog, domestic animals also became ill, and some died. These illnesses resembled those observed in the human in that there was evidence of irritation of exposed mucous membranes of the respiratory tract.

18. Studies for dental caries, dental fluorosis, urinary excretion of fluoride, and fluoride content of bone, revealed no evidence that there was excessive inhalation or ingestion of fluoride in the community.

19. With the exception of such episodes as that of the October 1948 smog, long-term studies of mortality records and plant morbidity records indicate that the health of the people of Donora appeared essentially no different from that of nearby towns.

20. Although bronchial asthma and heart disease appeared to be somewhat more prevalent among persons in the Donora area than in the United States as a whole, studies of mortality data, when compared with those of nearby communities, indicated that death due to disease of the heart and respiratory system was not increased in Donora.

21. Mortality records showed that crises have occurred in Donora creating, occasionally, higher death rates due to cardiovascular disease. These crises are probably related to atmospheric conditions.

22. Among the autopsies performed there were three of persons who died during the smog and these showed acute change in the lungs characterized by capillary dilatation, haemorrhage, oedema, purulent bronchitis and bronchiolitis.

23. Chronic cardiovascular disease, the origin of which antedated the smog incident, was a prominent feature in the autopsies.

Summary of Atmospheric Studies

1. The zinc spelters are major contributors to the atmospheric pollution load with special reference to particulate matter and carbon monoxide.

2. The amount of contaminants discharged from the zinc spelters during the "test period" was approximately twice that which occurred during the "curtailed production" period.

3. The zinc plant waste heat boiler stacks are major contributors of atmospheric pollution with special reference to particulate matter and sulfur dioxide.

4. The zinc plant sintering operation is a major contributor to the atmospheric pollution load with particular reference to sulfur dioxide.

5. The acid plant is the main source of discharge of oxides of nitrogen into the atmosphere.

6. The contribution of the zinc ore roasters, Waelz plant, zinc dross and cadmium plants to the general atmospheric pollution load of the valley is not considered significant.

7. The blast furnace department, including the sinter plant, is a major contributor to the general atmospheric pollution load with special reference to particulate matter and carbon monoxide.

8. The open hearth furnace stacks are significant contributors of particulate matter to the atmospheric pollution load.

9. The blooming mill and wire mill, including nail galvanizing, are not considered important contributors to the general atmospheric pollution of the valley.

10. The blooming mill and steel mill boiler stacks are major sources of sulfur dioxide.

11. Domestic heating systems and local steam locomotives are significant contributors to the general atmospheric pollution of the valley with special reference to carbon monoxide, sulfur dioxide, and particulate matter.

12. The distribution of concentrations in the general atmosphere of sulfur dioxide, total particulate matter, zinc, lead, and cadmium showed variations which may be roughly correlated with sources of contaminants.

13. Sulfur dioxide showed the most even distribution, indicating the wide distribution of sources of sulfur dioxide.

14. Total particulate matter showed even distribution with the exception of the areas closest to the zinc plant, which were higher than the others.

15. Concentrations of zinc, lead, and cadmium were highest in the vicinity of the zinc plant.

16. Air-sampling Station No. 4 (representing an area in Webster directly across the river from the zinc spelters) showed higher concentrations for all contaminants than the other stations.

17. Concentrations of various contaminants when considered by time of the day indicated that the greater air stability at night and fluctuation in plant operations influenced concentrations found.

18. Low concentrations of chloride, fluoride, and oxides of nitrogen were found in the general atmosphere.

19. Samples of particulate matter obtained from home filters in Donora and a home filter in Monessen showed no significant difference in the composition of the samples with the exception of sulfur. A higher concentration of sulfur was found in the particulate matter collected during the smog period than in samples obtained from filters in operation after the smog.

20. A combination of a high degree of atmospheric stability and stagnation was found to be necessary and sufficient to cause an accumulation of airborne pollutants in the valley at Donora.

21. Local micro-turbulences within the valley at night appeared to distribute the particulate matter evenly throughout the valley as determined by morning visual observations.

22. Wind speeds during windy periods within the valley were lower than those at hill top with the decrease being greater for cross-valley flow than for parallel-to-valley flow.

23. Similarity of average concentrations at all stations for various wind directions for sulfur dioxide, total sulfur, and total particulate matter showed multiple sources of these contaminants while definite high concentrations of zinc and cadmium were found only downwind from the zinc plant (except for variable, low speed wind periods), indicating a single source for those elements.

24. In general a greater percentage of higher concentrations was found in the wind speed range of 0–3 mph and the next highest in the 10–22 mph range; lowest values being found in the 4–9 mph range.

25. The concentration of contaminants showed no significant relationship to relative humidity or temperature.

26. A definite relationship was found to exist between the concentration of contaminants and atmospheric stability.

Recommendations

1. Reduce the gaseous contaminants especially sulfur dioxide and particulate matter discharged from the sinter plant Cottrell stacks.
2. Reduce the particulate matter and carbon monoxide from the zinc spelters.
3. Reduce the particulate matter and sulfur dioxide discharged from the waste heat boiler stacks.
4. Reduce the discharge of oxides of nitrogen and acid mists from Gay-Lussac stacks.
5. Reduce the amount of particulate matter and carbon monoxide from the waste blast furnace gas.
6. Reduce the amount of carbon monoxide discharged from the stove and sinter stacks.
7. Reduce the amount of particulate matter discharged from the sinter plant and open hearth stacks.
8. Reduce the amount of particulate matter discharged from the waste heat and blast furnace boilers and the sulfur dioxide from the waste heat, steel and wire plant boilers.
9. Reduce the amount of particulate matter discharged from domestic heating systems, steam locomotives and steamboats.
10. Establish a program of weather forecasts to alert the community of impending adverse weather conditions so that adequate measures can be taken to protect the populace.

APPENDIX I

Manual

FOR USE OF THE FORM "HISTORY OF SMOG ILLNESS"

This form is to be used for obtaining the history of occurrence of illness in Donora, Pa., allegedly as a result of the smog which occurred there in October 1948. The form is to be filled in by public health nurses. It is desirable to keep at a minimum the number of persons utilizing this form in order that it may be completed in as uniform a manner as possible.

The form is to be filled out on house-to-house visits. It is obvious, therefore, that in some instances the data recorded on the form will be for the person giving the information to the collector. In other instances, the person referred to on the form will be a relative or a friend of the person giving the information.

USE OF THE FORM

The collector of the data will be given a series of forms for each household which she is to visit. The names of all the persons known to live in that household will be recorded on separate sheets before the data collector receives the forms. Each nurse will carry blank forms with her so that she may record findings on all *other* persons living in the household during the time of the smog.

Case number: This is to be left blank by the recorder.

Household number: A number will be assigned to each household before recorder obtains the sheets. Each nurse will insert the number on all additional histories that she makes up for those people not indicated by the census report. A household includes all people who live and eat together. Inquire if other people were living in the household during the smog, and obtain information on each of them.

Telephone number: Inquire if there is a telephone in the house. If so, record the number.

Date: Date interview is held.

Name of informant: Write out the full name of the person in the household who gives the information. If more than one person is giving the information, record the names of the others as well.

Relation: Here record the relationship of the informant to the person whose record is being obtained, such as: husband, son, daughter, mother, boarder, roomer, etc. If informant is talking about himself the relation will be "self."

Name: The name of the person on whom the data are being obtained.

Family physician: Self-explanatory. It is not necessary to give address unless it is other than Donora. If the informant states that there is no family physician, write the word "none."

Age: Record age at last birthday.

Sex: Self-explanatory.

Color: Encircle "N" for "non-white" for all other than white.

Marital status: Encircle "S" if single; "M" if married; "W" if widowed; and "D" if divorced or separated.

Occupational history: Record in order, beginning with the present occupation, going back to the one just before the present occupation, and then going back to the one before that.

Plant: Abbreviate where possible. Distinguish the three divisions of the local plant in the following manner: Zinc, Steel and Wire Plant.

Location: If the plant is in Donora leave the space blank. If it is in some other place, note town and State or county.

Department and occupation: If the person being discussed is the informant, the department and occupation will be easily obtained. If the informant is other than the one employed obtain department and occupation, if possible.

Years: Self-explanatory. Fill in the years from the present to the year individual started working.

Residence history: This is an important part of this report and should be obtained with accuracy. Record only the street and the street number for people living in Donora. Include the name of the town if other than Donora, again recording *From* the present year, going back to the year when he arrived at that address. It will not be necessary to go back beyond 10 years for the information on residence history. If an individual has lived in the same area in Donora but has moved several times on the same block or nearby, it is not necessary to take down each house address.

Previous health status: First inquire about the general health both now and in the past. Such general questions should be asked as "Have you always been well?", "How has your health been?", "What sicknesses do you suffer from?" Try to avoid asking leading questions but get information about the conditions mentioned on this form.

Encircle the disease recorded only if it has been diagnosed by a physician.

Doctor's name: Fill in the name of the physician who made the above diagnosis; give his address if other than Donora.

Were you ever affected by smog in Donora: Ask this question this way, emphasizing the word "ever." Encircle "Y" or "N" for Yes or No, respectively, as the case may be.

When: Record the year or years. If he was affected in the period of October 28–31, 1948, record accordingly.

Were you in the Donora area October 28–31: Encircle "Y" or "N" for Yes or No, as the case may be.

At home: If he was not at his home, where did he stay during this period of time in Donora?

Affected by smog of October: Ask specifically if he was ill during the period of the October smog. Encircle "Y" or "N" for Yes or No, as the case may be. Obtain exact time of onset as near as is possible; for example, Wednesday, Thursday, Friday, Saturday, Sunday, or Monday, at 6 p. m. If the day is other than these days, then record the date and the hour, if possible. Record this information directly after the "Y" and "N" following "Affected by smog of October 28–31."

Symptoms: Ask the general question, "How did it affect you?" Try to avoid leading questions but obtain specific information about the items. Encircle the ones that they say they had and put a dash after each one that they do not mention. This will show that each item was discussed.

Cough: Encircle the term "cough," if he indicates that he did have cough. Encircle "Productive" or "Nonproductive," as the case may be.

Constriction of chest: Encircle this term if he had the sense of tightness or a feeling of pressure.

Dyspnoea: Ask about shortness of breath. Encircle if the answer is "Yes." Inquire when he had the difficulty in breathing—was it when walking up the hill, moving about in the house, while in bed, or all the time? Record this information in "remarks" if it is obtained.

Orthopnoea: The use of more than two pillows in sleeping at night is to be recorded as orthopnoea. If the individual had to sit in a chair or stand and lean his head against an object in order to get his breath put this information in "remarks."

Cyanosis: Encircle "cyanosis" if the individual says his fingernails or lips were blue or purple. Do not put the words "blue" or "purple" into his thinking. Instead, inquire if he noticed any difference in the color of the person's face, lips, hands, or fingernail beds.

Fever: Encircle "fever" if the temperature was recorded by thermometer and was over 99° or if the physician said he had a fever.

Smarting of eyes: Inquire specifically about itching, burning, or any other discomfort of the eyes. Record accordingly. Ask: "Did your eyes feel any different?" if no information is offered voluntarily.

Lacrimation: Encircle this if the individual's eyes "watered."

Soreness of the throat: Inquire as to the presence of some irritation of the throat. Ask if the throat felt dry and if there was any difficulty in swallowing.

Nasal discharge: Inquire as to the occurrence of watery fluid coming from the nose. Ask if he felt like he had a cold.

Nausea: The term "nausea" is to be encircled if the informant tells you that nausea occurred. The term "vomiting" is to be encircled if the informant tells you that he or she had an attack of vomiting.

Other: Record here any other symptoms which were complained of during the period referred to.

How many days ill: Ask specifically about the number of days disabled, away from school, or away from work during that period of time. Encircle the number of days, if it is from 0 to 5. If it is more than 5, record the number after the word "more."

Attended by: Record here the name of the physician, if known. Record here that he was attended by a doctor if he was, even if he did not know the name of the doctor. Record here Red Cross, fire department, neighbor, or whoever gave care.

Hospital: If he was in a hospital, encircle "Y" or "N" for Yes or No, as the case may be.

Name of hospital: Record the name of the hospital. Give address if outside of Donora.

Did you receive oxygen therapy: Encircle "Y" or "N" or "Not known," as the case may be.

Any symptoms at present: Avoid leading questions. Inquire as to the presence, at the time that you are obtaining this information, of any symptoms allegedly as a result of the smog. Do *not* ask, "Do you still have a cough?" or "Do you have constriction of the chest?" Ask the following questions: "How are you feeling now?" "Do you have any ill effects from the smog?" If the answer is "Yes," then ask what the sypmtoms are and record accordingly. Encircle those indicated.

Did you ever have pneumonia: Encircle "Y" or "N" for Yes or No as the case may be.

When: Record the year or years, recording also the number of times he had pneumonia during any year; for example, 1x1942; 2x1945.

How many colds have you had in 1948: Encircle the applicable number.

How many colds per year did you have before coming to Donora: Encircle the applicable number if known. Write "Unknown" if the informant does not know. If the individual has lived in Donora for more than 10 years, draw a line through the numbers.

Housing: Encircle G, F, P if the house seems in good condition, fair, or poor accordingly in the eyes of the nurse. Do not ask about the house but observe its condition. If it is well-built and apparently in good condition, encircle G; if it appears to be in fairly good condition, encircle F; if the doors, windows, steps, etc., appear to be in poor condition, encircle P.

Remarks: Under this, record anything which applies to the smog situation and which was not previously covered.

Animals: Record if household has any animals on premises, and type of animal.

Animals affected: Record if any of the animals were affected by the smog.

Signature: The initials of the collector of the information will be recorded here.

APPENDIX II

Manual

FOR USE OF THE FORM "CLINICAL DATA ON AFFECTED PERSONS"

In order to obtain unanimity and uniformity in filling in the form, certain suggestions are made below which will assist the physicians collecting these data to interpret similarly the replies given. Only physicians will interrogate for data on this form.

Date: The date on which the form is being filled out.

Household number: From index file available in office.

Case number: To be filled in later.

Source: The term "source" applies to the source from which the information is obtained that the person was ill during the smog.

Name: Record here the name of the person for whom this history is being obtained. Record *last* name first.

Address: Record here the present address. Encircle Webster, Donora, or other, as the case may be.

Informant: If the person giving you the information is talking about himself, just encircle the term "self." If the person giving the information is not telling you about himself, record here the name of the person who is giving you the information, again recording *last* name first.

Relation to patient: Record here the relationship of the person giving the information to the person about whom the information is being given.

Birthplace: Record here the town, if in Pennsylvania. Otherwise, record State or country, if not in the United States.

Age: Record here the age at last birthday.

M. F.: Encircle "M" for male; "F" for female.

Color: Encircle "W" for white; "N" for non-white.

M. S. W. D.: Encircle "M" for married; "S" for single; "W" for widowed; "D" for divorced or for separated.

Residence history: You will inquire whether or not he has lived in Donora all his life. If he has, you will record "all life" directly under the term "residence history." You will then, also, record the years during which he has lived at the present address, disregarding any information about previous address. If, however, he had not lived in Donora all his life, you will inquire as to the two previous addresses, recording accordingly, together with the years during which he lived at those addresses.

Occupational history: If you are obtaining this information for a housewife or for a preschool or school child, you will record accordingly, indicating "housewife" or "preschool" or "school," omitting any other details. If, however, you are getting this information for a person who is employed, then you will record the name of the plant. Under "location" specify where the plant is, if it is not in Donora. Try to obtain information on specific occupation. Under "years" record the present occupation first, going back to the next occupation. Fill in only the four spaces.

Smog illness: It is suggested that you ask the informant just what his story is about; what happened to him allegedly as a result of the smog. Let him tell his story in great detail, and you be a good listener—offering as few suggestions as is possible and by encouraging him to tell his complete story. In this way you will obtain a great deal of information which you can then record in the proper spaces. You will, however, from time to time, make limited suggestions to get certain points clear which you need to have clarified.

Onset: Encircle the term "gradual" or "sudden" as the case may be; that is, did his symptoms start suddenly or did they come on gradually?

Location: Record here the exact place where he was at the time of the onset of his symptoms.

Time: Record here the hour of the day that his symptoms started, encircling a. m. or p. m. as the case may be. Encircle the day on which his symptoms started. If it was other than Wednesday, Thursday, Friday, Saturday, Sunday, or Monday, of the smog period of October, then record in the appropriate space the date on which his symptoms started.

Activity at time of onset: Obtain exact information as to what he was doing when his symptoms began, and record accordingly. Use the two lines provided for this information.

Others at same location: Find out how many persons were at the same location as that at which the patient became ill. Record number of men and women under "M" and "F".

How many became ill: Record here, as above, the number of persons who became ill; again dividing them into men and women under "M" and "F," respectively.

Symptoms: An attempt has been made here to condense the form so that the symptoms can be recorded in as small a space as possible. The term "own" refers to those symptoms which the informant tells you about of his own accord. "Sugg." refers to those symptoms about which you specifically ask him after he has completed telling you his own story. "Duration" refers to the duration of the symptoms, in days.

Check the appropriate spaces under "own" from the story which the informant gives you, recording, as well, the numerical order in which the symptoms occurred.

Under "sugg." check those symptoms about which you specifically ask him, omitting, of course, those which he already gave you. Indicate the numerical order in which the symptoms began, being sure that the symptoms which he gave you of his own accord conform with the suggested symptoms as far as numerical sequence is concerned. Note that there will be some symptoms which start at the same time. Those would have the same number.

Under "duration" record the duration in number of days,

or in part of day, those symptoms which you have obtained from him either voluntarily or by suggestion. If the symptoms are still present, record the term "now" under "duration."

Eye irritation: This refers to epiphora, smarting, burning, or redness.

Nasal discharge: Any increase in nasal discharge over the normal.

Odor: Any unusual odor should be noted here, with specific question as to whether or not it was a foul odor, an acid odor, or any pungent odor.

Taste: Any unusual taste in the mouth of either an acidic or of a metallic nature should be recorded accordingly.

Sore throat: Difficulty in swallowing, irritation, pain, or burning of throat are to be included here.

Dry throat: This is self-explanatory.

Cough: Record productive or nonproductive or both, as the case may be.

Color of sputum: Record color directly after the word "sputum" and check accordingly.

Dyspnoea: The physician will have to decide whether or not dyspnoea existed and check accordingly.

Orthopnoea: Besides the fact that he may have had to sit up to get his breath or had to lean forward to get his breath, orthopnoea will be checked if he had to use more than two pillows to sleep.

Wheezing: If the informant observed wheezing noises in his chest as he breathed, check this item.

Palpitation: This is self-explanatory.

Fever: Record the actual temperature directly after the word "fever" if a thermometric reading was made. Check only if the temperature was above 99°.

Chills: Record here whether or not they had chilly sensations or actual chills.

Chest discomfort: Check the type of chest discomfort noted, such as "retrosternal burning," "retrosternal pressure," "costal margin," "parasternal pressure," and "muscle soreness." "Costal margin" refers to costal margin discomfort; "muscle soreness" refers to muscle soreness of the chest or thoracic region of the back muscles.

Epigastric distress: Record any epigastric distress here.

Nausea: Self-explanatory.

Vomiting: Self-explanatory.

Anorexia: Self-explanatory.

Abdominal pain: Record here only any abdominal discomfort other than epigastric distress.

Abdominal pressure: This refers to a sense of pressure of which some of the persons may have complained. Record accordingly.

Ankle oedema: Self-explantory.

Cyanosis: Self-explanatory.

Headache: Self-explanatory. If it is posible to obtain the location, record accordingly.

Weakness: Self-explanatory.

Other: Space has been provided for any symptoms not recorded above. These should be recorded here in any order in which you were able to obtain them.

Any medical treatment: "Yes" or "No", as the case may be, if the informant actually received *medical* treatment. Encircle the term "physician" or "hospital" if the answer to the medical treatment was "Yes." Obtain name of the physician, and address if other than Donora. If you have encircled "hospital," to indicate that hospitalization occurred, record the name of hospital.

Days ill: Record the number of days that he was ill with or without medical treatment. The term "ill" refers only to the occurrence of lost time from work or from school, or inability, in the case of the housewife to do her usual work.

Past illnesses: The purpose of this section is to determine whether or not certain past illnesses were related to the occurrence of symptoms as a result of the smog. You will ask questions to elicit this information in your own way and encircle the appropriate term.

Does smog aggravate or bring on attacks of the above: Self-explanatory.

Allergic history: The purpose of the allergic history is to obtain information as to whether or not an allergic history was more likely to have been associated with illness due to the smog. The terms "skin-rash," or "urticaria," "hay fever," and "asthma," are self-explanatory, and you will ask questions accordingly as you see fit. "Self" refers to the informant.

APPENDIX III

Why Is October the Optimum Month for Smog at Donora?[1]

In the following discussion an hypothesis is offered to explain why October seems to be the critical month for the occurrence of smog at Donora. Since it has been demonstrated that meteorological conditions favorable for extreme smog are associated with stagnant, deep anticyclones the problem is to explain why this type of anticyclone occurs more frequently in October in the Donora area than in any other month.

According to Wexler (*1*, *2*) a polar anticyclone is caused by extreme radiative cooling from snow-covered ground during the polar night. This radiative cooling from below creates a thermally stable, shallow anticyclone (ordinarily less than 3 kilometers deep). When this anticyclone moves southward and penetrates south of the westerlies, it is then located very favorably for dynamic processes to increase the intensity and height of the anticyclone. According to Rossby (*3*, *4*) lateral frictional stresses created by the lateral wind shear in the westerlies drag the slower moving air located to the south, thus causing supergradient winds which, because of the Coriolis force of the rotating earth, fling the air southward; air then moves down through isentropic surfaces by radiational cooling. Wexler (*5*) used this theory as a basis for an explanation of the transformation of a shallow, cold polar anticyclone into the warm, deep, "dynamic anticyclone." If the descending air flung southward and downward from the westerlies cannot reach the ground, and thus move across the surface isobars by surface frictional forces, the air will accumulate and build up a deeper and more intense anticyclone. The polar air, whose radiatively caused thermal stability has been accentuated by subsidence of the cold dome, provides a "shielding layer" which prevents the descending air from coming under the influence of the surface frictional stresses, and thus from moving away from the area.

Wexler (*5*) studied such a transformation process during the period May 20–23, 1936, an anticyclogenesis which was first analyzed by Simmers (*4*). In that case as the shallow polar anticyclone moved southward over the Great Lakes and south of the westerlies, a weak upper anticyclone moved from the southwest plains area to join with it. This upper anticyclone became centered over and moved with the point of greatest stability of the polar air below. The anticyclonic circulation built up from a height of 2 kilometers at Fargo, South Dakota, to at least 12 kilometers 3 days later; this was accompanied by an increase in central pressure from 1,029 millibars to 1,039 millibars.

Turning now to the meteorological conditions associated with the smog period of late October 1948, on the 22d of October a polar anticyclone entered the United States from Canada at the Montana border. It traveled to South Dakota on the 23d, to southern Wisconsin on the 24th, to Detroit on the 25th, oscillated over Ohio on the 26th to the 28th, was in northern Pennsylvania on the 29th, central New York on the 30th, and on the 31st traveled rapidly southward through eastern Virginia and North Carolina and on out to sea. Its central pressure increased by 6 millibars from the 23d to the 25th, decreased 8 millibars by the 27th, and decreased slowly thereafter. An upper, warm anticyclone moved on the 700 millibar surface from southern Louisiana to Oklahoma on the 23d and to southwestern Kansas on the 24th in such a direction as to approach the southeastward moving polar anticyclone. On the 25th it was located between Oklahoma and Kansas, on the 26th in southeastern Missouri, on the 27th in eastern Kentucky, and on the 28th to 30th it hovered over eastern Kentucky and on the 31st it, too, headed southward toward Georgia. At 500 millibars an anticyclonic center first appeared on the 25th over Kansas and thereafter moved in conjunction with the center at 700 millibars. As in the May 1936 case the upper, warm anticyclone remained generally to the south and west of the surface anticyclone and moved parallel to it. The sharp "refraction" of the paths of the surface and upper anticyclones at the Atlantic coast evidently caused by destruction of the oceanic portion of the shielding layer by heating from below is remarkably similar in the two cases.

Although an aerological analysis of the October 1948 case comparable in completeness to that of the May 1936 case has not been done, there is enough similarity in the motion of the surface and upper anticyclonic centers to suggest that the dynamic processes operating are the same. The near conjunction of the stable, subsiding lower anticyclone and the upper anticyclone gives just those conditions of great stability and weak winds to great heights which Willett points out are necessary for smog formation (*6*).

But why is October apparently the most favorable month for smog at Donora? Before attempting to answer this question let us summarize briefly the dynamic conditions necessary for a deep warm anticyclone to form and persist over a given area. The conditions are:

1. The area must lie on the southern edge of the westerlies.
2. The westerlies must possess large enough cyclonic curvature of the lateral wind-profile (looking downstream) to provide the frictional drive for the reverse vertical circulation cell which creates the descending current south of the westerlies.

[1] By H. Wexler, U. S. Weather Bureau. A suggested hypothesis is presented which will be developed more fully in a later paper.

TABLE 1.—*Conditions favorable for persistent anticyclogenesis*

Season (characterized by a single month)	Latitude (degrees) southern edge of the westerlies [1]	Average lateral wind shear south of the maximum westerlies in meters per second per degree of latitude [2]	Maximum speed of the westerlies in meters per second [3]	Shielding layer	Radiation conditions
Winter (January)	31	0.50	13.0	Frequent and strongly developed	Very favorable.
Spring (April)	33	.55	10.3	Frequent and moderately developed	Favorable.
Summer (July)	47	.42	7.2	Infrequent and weak	Very unfavorable.
Autumn (October)	39	.46	8.2	Frequent and moderately developed	Favorable.

[1] Defined by the average latitude over the United States of the southernmost isobar which completely encircles the earth at 10,000 feet. For all 4 months this turns out to be the 705-millibar isobar (7).
[2] Computed from unpublished material in files of the Extended Forecast Section, U. S. Weather Bureau. The average shear was computed from the maximum westerlies southward to the nearest band of zero-shear. It was not practicable to compute the actual curvature, but it is believed that the average shears computed in this way give a good estimate of the resultant frictional drag on the air south of the westerlies maximum.
[3] Taken from unpublished material in the files of the Extended Forecast Section.

3. The westerlies while strong enough to create the necessary lateral frictional stresses, should not be so strong as to prevent stagnancy of the ridge and trough pattern of the westerlies. That is, assuming a deep anticyclonic center has been formed, this will create an anticyclonic ridge in the westerlies. If the westerlies are too strong this anticyclonic perturbation and its accompanying surface anticyclone will not persist over the area but will move eastward.

4. The presence of a persistent shielding layer, introduced either by the penetration south of the westerlies of a subsiding shallow polar anticyclone, or by some geographical feature, is required to block the return flow of the descending current and thus cause the accumulation of air which is necessary for the creation of a deep anticyclone.

5. The presence is necessary of suitable radiational conditions exemplified by long clear nights and short days to maintain the surface inversion. The surface inversion will be the more resistant to destruction by insolation if the moisture content of the air is sufficiently large that a deep fog or stratus layer is caused by the nocturnal cooling.

Let us examine in table 1 of this appendix how satisfactorily on the average each season, as characterized by a single month, fulfills the above five requirements.

It is seen in appendix table 1 that only in summer and autumn are the westerlies located sufficiently far north on the average for the descending current to be found over the Donora vicinity (latitude about 40°). Of the remaining 4 points autumn leads in 3 (shear, shielding layer and radiation) and summer in 1 (low strength of the westerlies). In winter, although the lateral friction effects, the shielding layer, and radiation conditions are most favorable the strength of the westerlies and their extreme southerly displacement are decidedly unfavorable. Spring which is quite similar to autumn in shielding layer and to a slightly lesser extent in radiational aspects, differs materially in position, strength, and lateral shear of the westerlies which are quite winterlike in aspect.

The discussion above is confined to average conditions since frequencies were not available; it is believed that these averages serve as a good first approximation to the actual frequencies. The reasoning used here does not in any sense preclude the possibility of stagnant deep anticyclones occurring over the northeastern United States in any season but attempts to show that autumn, possessing the largest number of favorable factors, would have the greatest frequency of such phenomena, with winter probably having the next largest frequency. The autumnal and early winter maxima in closed anticyclonic circulation in the eastern United States are illustrated quite strikingly in the normal monthly sea-level pressure charts (*8*) where only the October, November, December, and January normal monthly maps have closed anticyclonic centers with, however, the October anticyclone located farthest north, over West Virginia.

If a persistent anticyclone did occur over the Donora region in the warm season, the intense solar heating during the long days would destroy the surface inversion and so prevent the accumulation of pollution, which is required over a period of 2 to 3 days to produce a smog.

Some interesting statistical information on anticyclones is found in unpublished material recently derived from the 40 years' series of daily northern hemisphere weather maps (*9*). This material consists of charts showing the monthly frequencies of anticyclonic centers by 5° longitude and latitude quadrangles. From these charts the highest frequency for each month was picked for eastern North America (east of the ninety-fifth meridian). These figures and localities in which they occur are presented in appendix table 2.

The maximum frequency of anticyclones is found farthest south (Alabama) in March, and farthest north (Lake Superior) in August. This is in good agreement with the annual

TABLE 2.—*Maximum frequency by month of anticyclones in eastern North America*

Month	Maximum frequency	Locality
January	59	Virginia.
February	50	Do.
March	43	Alabama.
April	41	Lake Erie.
May	43	West Virginia.
	42	Lake Erie.
June	47	Lake Michigan.
July	64	Lake Erie.
August	69	Lake Superior.
September	67	West Virginia.
October	95	Do.
November	77	Do.
December	58	Do.

south-north movement of the westerlies indicated in appendix table 1. The high incidence of anticyclones in summer over the Great Lakes also emphasizes the importance of the "shielding layer" in promoting anticyclogenesis once the westerlies are located in a favorable position. In summer the surface-water temperatures of the Great Lakes are lower than the temperatures of the air coming from the heated land surfaces and this phenomenon causes a surface inversion to form over the Lakes. The autumn and early-winter maxima of anticyclones in West Virginia are probably assisted by a "shielding layer" created by cold-air drainage in the numerous deep valleys which characterize this area and which assist in "trapping" the descending air thrown southward by the westerlies.

By far the largest monthly frequency, 95, is found in October in West Virginia, which lends additional support for the contention that October is the critical month for meteorological conditions favorable for smog in the eastern United States.

Appendix III References

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